

AD-A061 088

AIR FORCE GEOPHYSICS LAB HANSCOM AFB MASS
STEADY-STATE MULTI-ION DISTURBED D-REGION MODEL.(U)

F/G 4/1

UNCLASSIFIED

JUN 78 W SWIDER, C I FOLEY
AFGL-TR-78-0155

NL

1 OF 1
AD
A061088



END
DATE
FILMED
2 -79
DDC

DDC FILE COPY AD A061088

LEVEL II

AFGL-TR-78-0155
ENVIRONMENTAL RESEARCH PAPERS, No. 636

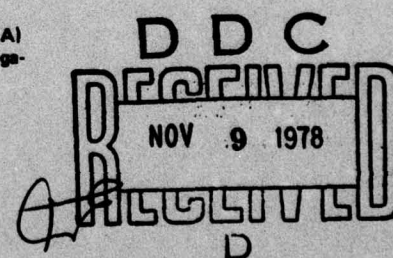


Steady-State Multi-Ion Disturbed D-Region Model

WILLIAM SWIDER
CAROL L. FOLEY

15 June 1978

This research has been funded in part by the Defense Nuclear Agency (DNA) under subtask S99QAXHDO28, Work Unit 46 entitled "Theoretical Investigations of Disturbed Ionospheres."



AERONOMY DIVISION PROJECT DO28
AIR FORCE GEOPHYSICS LABORATORY
HANSCOM AFB, MASSACHUSETTS 01731

AIR FORCE SYSTEMS COMMAND, USAF



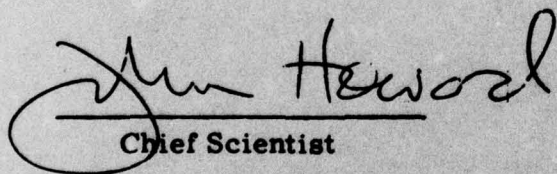
DISTRIBUTION STATEMENT A
Approved for public release;
Distribution Unlimited

78 10 27 044

This report has been reviewed by the ESD Information Office (OI) and is releasable to the National Technical Information Service (NTIS).

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER


Chief Scientist

Qualified requestors may obtain additional copies from the Defense Documentation Center. All others should apply to the National Technical Information Service.

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AFGL-TR-78-0155	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) STEADY-STATE MULTI-ION DISTURBED D-REGION MODEL	5. TYPE OF REPORT & PERIOD COVERED Scientific. Interim.	
7. AUTHOR(s) William Swider Carol I. Foley	6. PERFORMING ORG. REPORT NUMBER ERP No. 636	
9. PERFORMING ORGANIZATION NAME AND ADDRESS Air Force Geophysics Laboratory (LKD) Hanscom AFB Massachusetts 01731	8. CONTRACT OR GRANT NUMBER(s)	
11. CONTROLLING OFFICE NAME AND ADDRESS Air Force Geophysics Laboratory (LKD) Hanscom AFB Massachusetts 01731	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 62704H D028CD01	
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	12. REPORT DATE 15 June 1978	
	13. NUMBER OF PAGES 45	
	15. SECURITY CLASS. (of this report) Unclassified	
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report) AFGL-TR-78-0155, AFGL-ERP-636		
18. SUPPLEMENTARY NOTES This research has been funded in part by the Defense Nuclear Agency (DNA) under subtask S99QAXHD028, Work Unit 46 entitled "Theoretical Investigations of Disturbed Ionospheres." *Boston College		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) D-region ionization Solar proton event (SPE) Disturbed D-region D-region model Polar cap absorption (PCA) event Environmental research papers,		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) A model with 78 reactions involving 21 positive ions and 8 negative ions has been developed for the disturbed D-region under steady-state conditions. Model examples are given for the 2 to 5 November 1969 and 3 to 11 August 1972 solar proton events. The computer program for the model is given in the Appendix.		

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

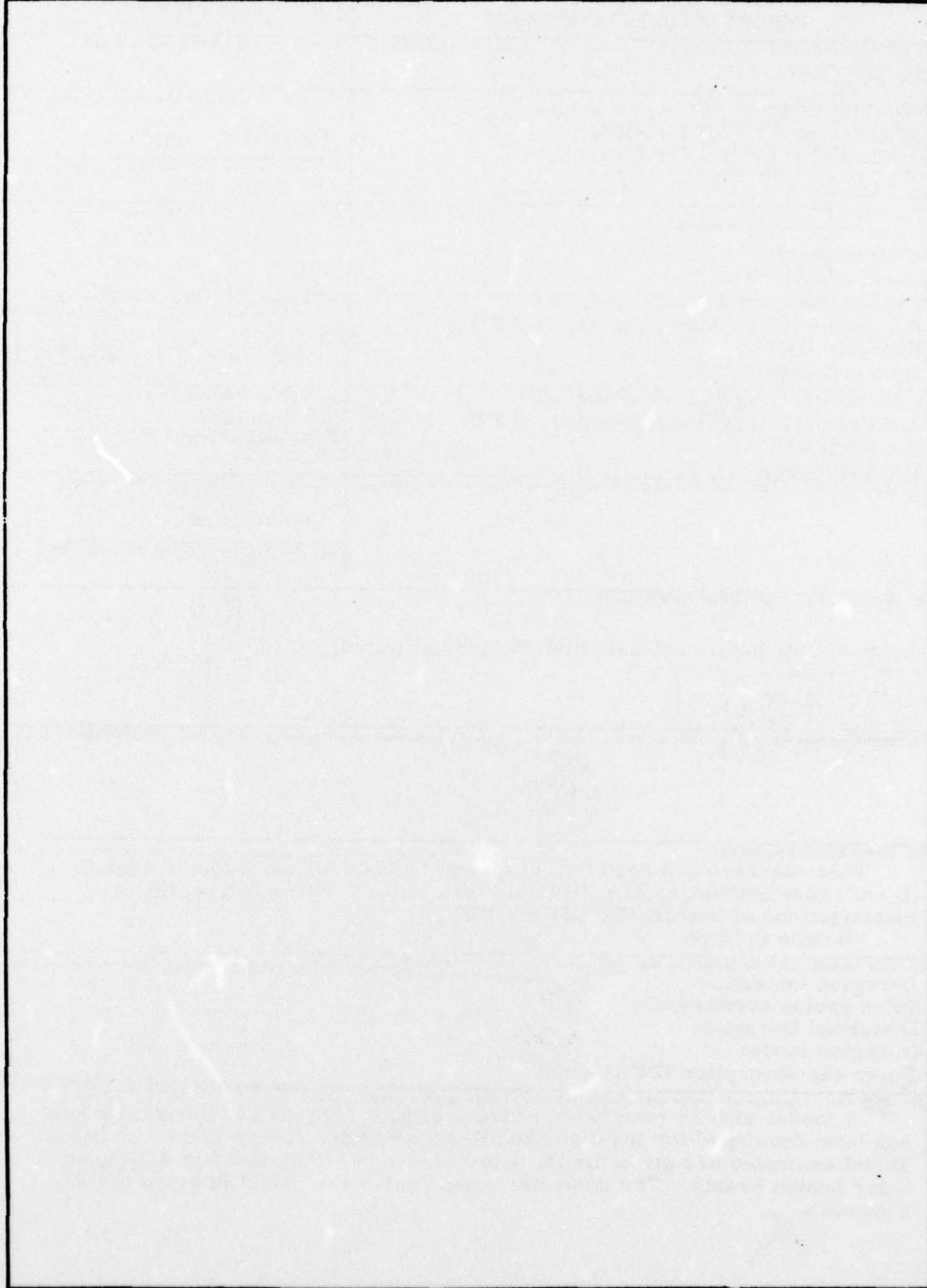
Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

409 578

slr

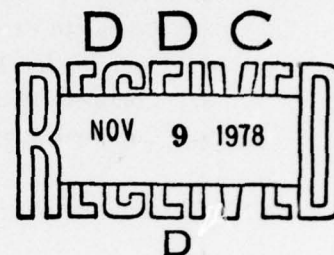
SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)



SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

LEVEL II

ACCESSION NO.	
DTIC	White Section <input checked="" type="checkbox"/>
DDC	Diff Section <input type="checkbox"/>
UNANNOUNCED	<input type="checkbox"/>
JUSTIFICATION	
BY	
DISTRIBUTION/AVAILABILITY CODES	
Dist.	AVAIL. and/or SPECIAL
A	



Contents

1. INTRODUCTION	5
2. OUTLINE OF MODEL	6
3. NUMERICAL EXAMPLE: 2 November 1969 SPE	10
4. NUMERICAL EXAMPLE: Nighttime	19
5. NUMERICAL EXAMPLE: August 1972 SPE	24
REFERENCES	29
APPENDIX A: Steady-State Multi-Ion Disturbed D-Region Model Program	31

Illustrations

1. Measured and Computed Electron Concentrations for Rocket B-4 Launched at 2110 UT, 2 November 1969	12
2. Principal Positive Ions Computed (Table 3) for Rocket B-4	13
3. Principal Negative Ions Computed (Table 3) for Rocket B-4	13
4. Principal Positive Ions Computed (Table 5) for 0605 UT, 3 November 1969, the Time of Launch for Black Brant Rocket 17.758	19
5. Principal Negative Ions Computed (Table 5) for 0605 UT, 3 November 1969	20

Tables

1. Positive Ion Reactions	8
2. Negative Ion Reactions	10
3. Complete Printout of Calculations for 2100 UT, 2 November 1969	14
4. Same as for Table 3 Except k_{43} as in Table 1	17
5. Complete Printout of Calculations for 0605 UT, 3 November 1969	21
6. Complete Printout of Calculations for 1508 UT, 4 August 1972	26

Steady-State Multi-Ion Disturbed D-Region Model

1. INTRODUCTION

Previously¹ we described a model for the nighttime disturbed D-region which treated negative ions in a highly simplified manner. Good agreement was attained² between the model and the nighttime observations of 3 November 1969 at Ft. Churchill, Canada, during a solar proton event (SPE). More recently, by incorporating the latest negative ion chemistry, exclusive of hydration processes, we have found³ that good agreement can be obtained between our latest model and the three daytime observations of 2, 3, and 4 November 1969 for this same event and location. In this report we document the new program which includes not only a more satisfactory treatment of negative ions, but also includes some new positive ion chemistry involving NO^+ ions. We also provide here the numerical results obtained in applying this program to the solar proton events of 2 to 5 November 1969 and 3 to 11 August 1972.

(Received for publication 14 June 1978)

1. Swider, W., and Foley, C.I. (1975) Computer Program for the Disturbed Steady-State Nighttime D-region, AFCRL-TR-75-0150.
2. Swider, W., and Narcisi, R.S. (1975) A study of the nighttime D-region during a PCA event, J. Geophys. Res. 80:655-664.
3. Swider, W., Keneshea, T.J., and Foley, C.I. (1978) An SPE-disturbed D-region model, Planet. Space Sci. 26:

2. OUTLINE OF MODEL

The computer program is reproduced in Appendix A. All photorates in this code are multiplied by DD which is set to 1 for daytime and 0 for nighttime.

The iterative scheme developed to solve for all species concentrations is similar to that derived before.¹ The present scheme is more complex; two initial concentrations are now needed, one for electrons and one for the positive ion sum. Using the initial concentrations for electrons [e], and the positive ion sum, SP, the individual negative ions are determined and then summed, the sum denoted by NSUM. Then the positive ions are individually calculated and summed, PSUM. A new $[e] = \left\{ \text{previous } [e] + \text{PSUM}/(1+\lambda) \right\} / 2$, where $\lambda = \text{NSUM}/\text{previous } [e]$, and a new $\text{SP} = \left\{ \text{previous } [e] + \text{NSUM} + \text{PSUM} \right\} / 2$ are then determined. This sequence is repeated until PSUM agrees with NSUM+[e] to some desired precision, usually ± 1 percent. In the examples to be shown later, not more than 9 iterations were required at any particular altitude (40-90 km) in order to attain this criterion.

Initial daytime electron concentrations were obtained from

$$[e] = (q/\text{SI})^{1/2} \quad (1) \text{ L } 189$$

where $\text{SI}=\psi$ represents values for the effective electron loss coefficient as determined⁴ for the 2 to 5 November 1969 SPE. The number following the equation number in the text, as L 189 above, means that Eq. (1) is or begins on line 189 of the program. Initial nighttime electron concentrations were estimated, as before,¹ from the equation⁵

$$[e] = \left\{ (L(A)/2\alpha_D)^2 + q/\alpha_D \right\}^{1/2} - L(A)/2\alpha_D \quad (2) \text{ L } 191$$

where α_D is the mean dissociative recombination coefficient and

$$L(A) = k_{61}[\text{O}_2]^2 + k_{62}[\text{O}_2][\text{N}_2] \quad (3) \text{ L } 187$$

is the loss rate (sec^{-1}) of electrons by attachment to O_2 with O_2 and N_2 as third bodies. The reaction rates and rate coefficients are listed later, the subscripts for k referring to the processes are as numbered in that listing

4. Swider, W., and Dean, W.A. (1975) Effective electron loss coefficient of the disturbed daytime D-region, J. Geophys. Res. 80:1815-1819.
5. Swider, W., Narcisi, R.S., Keneshea, T.J., and Ulwick, J.C. (1971) Electron loss during a nighttime PCA event, J. Geophys. Res. 76:4691-4694.

Initial total positive ion concentrations were determined from the expression

$$SP = \left\{ q \left(\frac{5[O]}{\alpha_D} + \frac{[O_3]}{\alpha_i} \right) / (5[O] + [O_3]) \right\}^{1/2} \quad (4) \text{ L193}$$

where α_i is the mean ion-ion recombination coefficient. The multiplicative factor for $[O]$, somewhat arbitrary, was selected after some trial runs as a factor for improving SP vis-a-vis the final calculated positive ion sum. Equation (4) simplifies to the familiar expressions $(q/\alpha_D)^{1/2}$ at high D-region altitudes where $[O] \gg [O_3]$ and $(q/\alpha_i)^{1/2}$ at low D-region altitudes where $[O_3] \gg [O]$. Values chosen for α_D and α_i were $4 \times 10^{-7} \text{ cm}^3/\text{sec}$ (L 73) and $6 \times 10^{-8} \text{ cm}^3/\text{sec}$ (L 74) respectively. The former value was selected as that typical for a mixture of NO^+ and O_2^+ ions at D-region temperatures, whereas the latter value is based upon laboratory measurements by Smith et al.⁶ The fact that all ion-ion recombination coefficients were set at $6 \times 10^{-8} \text{ cm}^3/\text{sec}$ in this program is in accord with the laboratory work. However, this constraint is not a necessary one in the operation of this program; one α_i being required only for initial SP.

The positive ion equations are similar to those listed before except that changes have been made because of our inclusion of photodissociation processes for O_4^+ and O_2^+ (H_2O) ions and by our addition of the ions NO^+ (N_2), NO^+ (H_2O) (N_2), NO^+ (H_2O) (CO_2), NO^+ ($2\text{H}_2\text{O}$) (N_2) and NO^+ ($2\text{H}_2\text{O}$) (CO_2). The list of positive ion reactions, numbered 4 through 52 in Table 1 for the 21 positive ions considered, is fairly complete. Rate coefficients are generally from the same sources already identified.^{2,3} Rates for photodissociation processes 4 and 5 in Table 1 are from Vanderhoff and Niles,⁷ while the rate coefficient k_{43} was taken from the work of Johnsen et al.⁸ Rate coefficients for reactions 45 and 48 were set equal to that for k_{43} . The rate coefficient k_{51} is based⁹ upon parameters measured by Johnsen et al.⁸ High rate coefficients for processes 44, 46, 47, 49 and 50 were chosen in accordance with the fact that they are all "switching" reactions. Computation of the individual positive ions begins with O_2^+ (PION 4, J), line 204 of the program and is completed by line 257 with PION (24, J) = H_9O_4^+ . Thus, this rather extensive list of positive ions (21) requires only 53 lines in the computer program.

6. Smith, D., Adams, N.G., and Church, M.J. (1976) Mutual neutralization rates of ionospherically important ions, Planet. Space Sci. 24:697-703.
7. Vanderhoff, J.A., and Niles, F.E. (1976) Recent development in measurements of photodissociation for atmospheric positive ions, EOS, 57:303.
8. Johnsen, R., Huang, C.-M., and Biondi, M.A. (1975) The formation and breakup of $\text{NO}^+\cdot\text{N}_2$ clusters in N_2 at low temperatures, J. Chem Phys. 63:3374-3378.
9. Heimerl, J.M. (1976) Values for Selected Collisional Dissociation Rate Coefficients of Positive Clustered Ions, BRL-IMR-499.

Table 1. Positive Ion Reactions. Units for photo-processes, two-body and three-body processes are sec^{-1} , cm^3/sec and cm^6/sec , respectively. The various process coefficients, $\kappa = A (T/300)^B e^{D/T}$, are presented in the format A B D

					A	B	D
4	$\text{O}^+ + \text{H}\nu$	$= \text{O}^+ + \text{O}^+$			$3.00\text{E}-01$		
5	$\text{O}^+ + \text{H}_2\text{O} + \text{H}\nu$	$= \text{O}^+ + \text{H}_2\text{O}$			$6.00\text{E}-01$		
6	$\text{O}^+ + \text{N}_2$	$= \text{O}^+ + \text{O}^+$			$4.50\text{E}-10$		
7	$\text{O}^+ + \text{O}_2 + \text{O}_2$	$= \text{O}^+ + \text{O}_2$			$3.30\text{E}-30$	-3.2	
8	$\text{O}^+ + \text{O}$	$= \text{O}^+ + \text{O}^+$			$3.00\text{E}-10$		
9	$\text{O}^+ + \text{H}_2\text{O}$	$= \text{O}^+ + \text{H}_2\text{O}$			$1.50\text{E}-09$		
10	$\text{O}^+ + \text{H}_2\text{O} + \text{H}_2\text{O}$	$= \text{H}_3\text{O}^+ + \text{O}^+$			$1.00\text{E}-09$		
11	$\text{O}^+ + \text{H}_2\text{O} + \text{H}_2\text{O}$	$= \text{H}_3\text{O}^+ + \text{OH} + \text{O}^+$			$2.00\text{E}-10$		
12	$\text{H}_3\text{O}^+ + \text{H}_2\text{O}$	$= \text{H}_5\text{O}_2^+ + \text{OH}$			$1.40\text{E}-09$		
13	$\text{H}_3\text{O}^+ + \text{N}_2 + \text{N}_2$	$= \text{H}_3\text{O}^+ + \text{N}_2$			$1.40\text{E}-30$	-2.0	
14	$\text{H}_3\text{O}^+ + \text{N}_2 + \text{CO}_2$	$= \text{H}_3\text{O}^+ + \text{CO}_2$			$1.00\text{E}-09$		
15	$\text{H}_3\text{O}^+ + \text{CO}_2 + \text{H}_2\text{O}$	$= \text{H}_5\text{O}_2^+ + \text{CO}_2$			$1.00\text{E}-10$		
16	$\text{H}_5\text{O}_2^+ + \text{CO}_2 + \text{H}$	$= \text{H}_5\text{O}_2^+ + \text{CO}_2 + \text{H}$			$3.00\text{E}-30$		
17	$\text{H}_5\text{O}_2^+ + \text{CO}_2 + \text{H}_2\text{O}$	$= \text{H}_7\text{O}_3^+ + \text{CO}_2$			$1.00\text{E}-10$		
18	$\text{H}_3\text{O}^+ + \text{H}_2\text{O} + \text{H}$	$= \text{H}_5\text{O}_2^+ + \text{H}$			$3.50\text{E}-27$	-3.0	
19	$\text{H}_5\text{O}_2^+ + \text{H}_2\text{O} + \text{H}$	$= \text{H}_7\text{O}_3^+ + \text{H}$			$2.20\text{E}-27$	-3.0	
20	$\text{H}_7\text{O}_3^+ + \text{H}_2\text{O} + \text{H}$	$= \text{H}_9\text{O}_4^+ + \text{H}$			$2.30\text{E}-27$	-3.0	
21	$\text{NO}^+ + \text{CO}_2 + \text{N}_2$	$= \text{NO}^+ + \text{CO}_2$			$3.00\text{E}-29$	-2.0	
22	$\text{NO}^+ + \text{CO}_2 + \text{H}_2\text{O}$	$= \text{NO}^+ + \text{H}_2\text{O} + \text{CO}_2$			$5.00\text{E}-10$		
23	$\text{NO}^+ + \text{H}_2\text{O} + \text{H}_2\text{O} + \text{N}_2$	$= \text{NO}^+ + (\text{H}_2\text{O})_2 + \text{N}_2$			$1.10\text{E}-27$	-4.7	
24	$\text{NO}^+ + (\text{H}_2\text{O})_2 + \text{H}_2\text{O} + \text{N}_2$	$= \text{NO}^+ + (\text{H}_2\text{O})_3 + \text{N}_2$			$1.60\text{E}-27$	-4.7	
25	$\text{NO}^+ + (\text{H}_2\text{O})_3 + \text{H}_2\text{O}$	$= \text{H}_7\text{O}_3^+ + \text{HN}_2$			$7.00\text{E}-11$		
26	$\text{NO}^+ + \text{E}$	$= \text{N} + \text{O}$			$4.00\text{E}-07$	-1.0	
27	$\text{O}^+ + \text{E}$	$= \text{O} + \text{O}$			$2.00\text{E}-07$	-1.0	
28	$\text{O}^+ + \text{E}$	$= \text{O}^+ + \text{O}^+$			$2.00\text{E}-06$		
29	$\text{O}^+ + \text{H}_2\text{O} + \text{E}$	$= \text{O}^+ + \text{H}_2\text{O}$			$2.00\text{E}-06$		
30	$\text{H}_3\text{O}^+ + \text{OH} + \text{E}$	$= 2\text{H}_2\text{O}$			$2.00\text{E}-06$		
31	$\text{H}_3\text{O}^+ + \text{E}$	$= \text{H}_2 + \text{OH}$			$1.00\text{E}-06$		
32	$\text{H}_5\text{O}_2^+ + \text{E}$	$= \text{H}_2\text{O} + \text{H}_2 + \text{OH}$			$2.00\text{E}-06$		
33	$\text{H}_7\text{O}_3^+ + \text{E}$	$= 2\text{H}_2\text{O} + \text{H}_2 + \text{OH}$			$4.00\text{E}-06$		
34	$\text{H}_9\text{O}_4^+ + \text{E}$	$= 3\text{H}_2\text{O} + \text{H}_2 + \text{OH}$			$5.00\text{E}-06$		
35	$\text{H}_3\text{O}^+ + \text{N}_2 + \text{E}$	$= \text{H} + \text{H}_2\text{O} + \text{N}_2$			$2.00\text{E}-06$		
36	$\text{H}_3\text{O}^+ + \text{CO}_2 + \text{E}$	$= \text{H} + \text{H}_2\text{O} + \text{CO}_2$			$2.00\text{E}-06$		
37	$\text{H}_5\text{O}_2^+ + \text{CO}_2 + \text{E}$	$= \text{H} + 2\text{H}_2\text{O} + \text{CO}_2$			$3.20\text{E}-06$		
38	$\text{NO}^+ + \text{CO}_2 + \text{E}$	$= \text{NO} + \text{CO}_2$			$1.50\text{E}-06$		
39	$\text{NO}^+ + \text{H}_2\text{O} + \text{E}$	$= \text{NO} + \text{H}_2\text{O}$			$1.50\text{E}-06$		
40	$\text{NO}^+ + (\text{H}_2\text{O})_2 + \text{E}$	$= \text{NO} + 2\text{H}_2\text{O}$			$3.00\text{E}-06$		
41	$\text{NO}^+ + (\text{H}_2\text{O})_3 + \text{E}$	$= \text{NO} + 3\text{H}_2\text{O}$			$4.50\text{E}-06$		
42	$\text{O}^+ + \text{H}$	$= \text{O}^+ + \text{O}^+ + \text{H}$			$3.30\text{E}-06$	-4.0-5.03E+03	
43	$\text{NO}^+ + \text{N}_2 + \text{N}_2$	$= \text{NO}^+ + \text{N}_2$			$2.00\text{E}-31$	-4.4	
44	$\text{NO}^+ + \text{N}_2 + \text{CO}_2$	$= \text{NO}^+ + \text{CO}_2$			$2.00\text{E}-09$	0.0	
45	$\text{NO}^+ + \text{H}_2\text{O} + \text{N}_2 + \text{N}_2$	$= \text{NO}^+ + 2\text{H}_2\text{O} + \text{N}_2$			$2.00\text{E}-31$	-4.4	
46	$\text{NO}^+ + 2\text{H}_2\text{O} + \text{CO}_2$	$= \text{NO}^+ + 2\text{H}_2\text{O} + \text{CO}_2$			$2.00\text{E}-09$	0.0	
47	$\text{NO}^+ + 2\text{H}_2\text{O} + \text{CO}_2 + \text{H}_2\text{O}$	$= \text{NO}^+ + 2\text{H}_2\text{O} + \text{CO}_2$			$2.00\text{E}-09$	0.0	
48	$\text{NO}^+ + 2\text{H}_2\text{O} + \text{N}_2 + \text{N}_2$	$= \text{NO}^+ + 2\text{H}_2\text{O} + \text{N}_2$			$2.00\text{E}-31$	-4.4	
49	$\text{NO}^+ + 2\text{H}_2\text{O} + \text{CO}_2$	$= \text{NO}^+ + 2\text{H}_2\text{O} + \text{CO}_2$			$2.00\text{E}-09$	0.0	
50	$\text{NO}^+ + 2\text{H}_2\text{O} + \text{CO}_2 + \text{H}_2\text{O}$	$= \text{NO}^+ + 3\text{H}_2\text{O} + \text{CO}_2$			$2.00\text{E}-09$	0.0	
51	$\text{NO}^+ + \text{N}_2 + \text{N}_2$	$= \text{NO}^+ + \text{N}_2 + \text{N}_2$			$1.00\text{E}-08$	-4.4-2.10E+03	
52	$\text{H}_9\text{O}_4^+ + \text{H}$	$= \text{H}_7\text{O}_3^+ + \text{H}_2\text{O} + \text{H}$			$1.20\text{E}-01$	-4.0-8.80E+03	

Eight negative ions are included in this program, O_2^- , O_4^- , CO_4^- , CO_3^- , O^- , O_3^- , NO_2^- and NO_3^- . This is also the order in which the respective ion concentrations are solved. Considerable algebraic manipulation was required for these solutions which will not be described in the text but can be followed in the subroutine REGION, lines 25-87. The ion concentrations of several ions are easily solved, but the main trick was to eliminate CO_3^- from the equation for O_2^- which was accomplished by reducing CO_3^- to a function of O_2^- . Thus, the solution of CO_3^- (line 64) is expressed simply as $S[O_2^-]/R$, but S, lines 35-39 and R, line 34, are quite complex terms involving the lengthy algebraic factors T, W, V, U, which are described on lines 29-32. The negative ion processes used in the calculations are given in Table 2. Rate coefficients for non-proton processes were taken mainly from the work of the Boulder group (for example, Ferguson)¹⁰ including a recent update¹¹ for $k_{80} + k_{81}$, 8.8×10^{-10} cm³/sec with product branches which we took as equal. Photodissociation/photodetachment rates are generally those listed by Peterson et al¹² or estimated by Niles¹³ (NO_x^-).

Profiles of neutrals O, O_2 , O_3 , $O_2(^1\Delta)$, N_2 , CO_2 , H_2O , NO and NO_2 plus temperature were required inputs to the computations. Total concentrations, [M], and temperatures T, were taken from CIRA^{*} 1972 for the appropriate month and latitude with $N_2 = 0.7808$ [M], $O_2 = 0.2095$ [M] and $CO_2 = 3 \times 10^{-4}$ [M]. Water vapor concentrations, $[H_2O]$ were set at 10^{-6} [M]. The choices for the other minor neutrals are described elsewhere.³ Each output gives a complete account of all the neutral concentrations utilized. The daytime and nighttime minor neutral concentrations used in the computations will be presented in typical printouts for daytime and nighttime situations.

10. Ferguson, E. E. (1975) in Atmospheres of Earth and the Planets (Ed. B. M. McCormac) Reidel, Dordrecht, Holland, pp 197-210.

11. Ferguson, E. E. (1977) Paper presented at IAGA meeting in Seattle, Washington,

12. Peterson, J. R., Cosby, P. C., and Moseley, J. T. (1977) Photo-destruction of atmospheric negative and positive ions, Space Res. 17:243-246.

13. Niles, F. E. (1976) private communication.

* COSPAR International Reference Atmosphere.

Table 2. Negative Ion Reactions. Units and format are as for Table 1

					A	B	D
60 O2-	+ O3	= O3-	+ O2		5.00E-10		
61 O2	+ E + O2	= O2-	+ O2		1.40E-29	-1.0-6.00E+02	
62 O2	+ E + N2	= O2-	+ N2		1.00E-31		
63 O2-	+ O	= O3	+ E		1.50E-10		
64 O2-	+ O	= O-	+ O2		1.50E-10		
65 O2-	+ O2(10)	= O2	+ O2 + E		2.00E-10		
66 O2-	+ O2 + O2	= O4-	+ O2		3.50E-31	-1.0	
67 O4-	+ CO2	= CO4-	+ O2		4.30E-10		
68 CO4-	+ O3	= O3-	+ CO2 + O2		1.30E-10		
69 CO4-	+ NO	= NO3-	+ CO2		4.80E-11		
70 CO4-	+ O	= CO3-	+ O2		1.50E-10		
71 O3-	+ O	= O2-	+ O2		3.20E-10		
72 O3-	+ CO2	= CO3-	+ O2		5.50E-10		
73 CO3-	+ O	= O2-	+ CO2		1.10E-10		
74 CO3-	+ NO	= NO2-	+ CO2		1.10E-11		
75 CO3-	+ NO2	= NO3-	+ CO2		2.00E-10		
76 NO2-	+ O3	= NO3-	+ O2		9.00E-11		
77 O-	+ O2 + O2	= O3-	+ O2		1.10E-30	-1.0	
78 O-	+ O	= O2	+ E		2.00E-10		
79 O-	+ O2(10)	= O3	+ E		3.00E-10		
80 O-	+ O3	= O3-	+ O		4.40E-10		
81 O-	+ O3	= O2-	+ O2		4.40E-10		
91 O2-	+ HV	= O2	+ E		6.60E-01		
92 O-	+ HV	= O	+ E		2.80E+00		
93 CO4-	+ HV	= CO2	+ O2 + E		6.00E-01		
94 CO3-	+ HV	= CO2	+ O-		4.00E-01		
95 NO2-	+ HV	= NO2	+ E		6.00E-02		
96 NO3-	+ HV	= NO2-	+ O		6.00E-02		
97 NO3-	+ HV	= NO	+ O2 + E		4.40E-03		

3. NUMERICAL EXAMPLE: 2 November 1969 SPE

Table 3 is a typical printout. It was generated specifically for the ionization production rate associated with the daytime electron SPE concentrations measured¹⁴ on 2 November 1969, Flight B4 at Ft. Churchill, Canada. Photodetachment/photodissociation rates $k_{91} - k_{97}$ have been doubled to improve the agreement between the data and the computations. The agreement is quite good, as seen in Figure 1. The results obtained with the "normal" Table 2 values for $k_{91} - k_{97}$ are discussed elsewhere³ in conjunction with the doubled rates. The rate coefficient k_{43} has been set to 0 in this example because NO^+ otherwise seemed to fall off faster with decreasing altitude than the data for this event admit.¹⁵ This NO^+ behavior is shown in Figure 2 which is a plot of the principal positive ions listed in Table 3.

14. Dean, W.A. (1972) in Proc. COSPAR Symp. on SPE of Nov. 1969, AFCRL-72-0474, pp 291-306.

15. Narcisi, R.S., Philbrick, C.R., Thomas, D.M., Bailey, A.D., Wlodyka, L.E., Baker, D., Federico, G., Wlodyka, R., and Gardner, M.E. (1972) in Proc. COSPAR Symp. on SPE of Nov. 1969, AFCRL-72-0474, pp 421-432.

Also shown in Figure 2 is an NO^+ profile obtained with $k_{43} \neq 0$, specifically, the value given in Table 1. The output associated with $k_{43} \neq 0$ is given in Table 4 minus the first part of the output which is the same as that for Table 3. The electron concentrations are somewhat higher for the first case, the greatest difference being near 78-80 km. This is because with $k_{43} \neq 0$, O_2^+/NO^+ is higher at 80 km and O_2^+ has a lower dissociative recombination coefficient, twice that of NO^+ (as adopted here, Table 1). In other words, for the same ionization production rate the electron concentration will be a factor $(2)^{1/2}$ greater if only O_2^+ ions are present as compared to solely NO^+ ions. Slightly lower electron concentrations are encountered near 75 km for the $k_{43} \neq 0$ case because conversion of NO^+ to oxonium ions leads to slightly higher electron loss since the latter ions have greater dissociative recombination coefficients than NO^+ (Table 1). Below 75 km, there is virtually no difference in $[e]$ for the two cases, because NO^+ contributes very little to the ion chemistry in either case. In fact, since O_2^+ is the precursor ion for the SPE situation, the choice of k_{43} is rather moot. Furthermore, inclusion of collisional breakup expressions for ions like NO^+ (N_2)(CO_2), would probably increase the NO^+ concentrations for the $k_{43} \neq 0$ case and further cloud the issue as to the role of NO^+ clustering in the D-region under SPE conditions. Another important factor not to be forgotten in regards to the NO^+ distribution is the fact that it depends strongly on the NO profile chosen. The NO profile selected is based in part upon its compatibility with the data² and is probably the strongest reason why our results should not be construed as giving a major clue as to the role of NO^+ clusters in the D-region.

Vanderhoff and Niles report⁷ that the photodissociation of oxonium is negligible considering the small cross-sections for the process. On the other hand, photodissociation cross-sections for O_4^+ , $\text{O}_2^+(\text{H}_2\text{O})$, and $\text{O}_2^+(\text{CO}_2)$ are large.¹⁶ We have included the recommended photodissociation rates for the first two species; processes 4 and 5 in Table 1. The inclusion of these rates had the effect of lowering the crossover point between the simple ions (NO^+ , O_2^+) and the oxonium ions by about 2 km. Thus, the effect is not a major one. A negligible further change in crossover point altitude was found when these rates were doubled to account roughly for scattered and reflected light as has been done for the rates $k_{91} - k_{97}$. Photodissociation of $\text{O}_2^+(\text{CO}_2)$ is not significant in the D-region because this species is not produced effectively at these altitudes.

16. Moseley, J. T., Cosby, P. C., and Peterson, J. R. (1977) Laboratory measurements of photodissociation and photodetachment cross-sections of atmospheric ions, EOS 58:698.

Although the daytime electron concentrations for 3 and 4 November 1969, besides the 2 November 1969 case shown here agree satisfactorily with the data,³ it should not be assumed that the negative ion problem is settled. The hydration of negative ions has been ignored (Figure 3), and this is undoubtedly unrealistic. The agreement noted therefore, only implies that the negative ion chemistry is satisfactory in regards to the electron distribution in daytime. Thus, negative ions like NO_2^- and NO_3^- that appear to have negligible photodetachment rates, may be hydrated to an important extent but have no impact upon the electron chemistry because electrons are presumably even less readily detached from NO_x^- hydrates. Formation of $\text{CO}_3^- (\text{H}_2\text{O})$ has been shown³ to be unimportant in the daytime because the photodestruction rate is large. Even sunset does not appear to be influenced³ by the omission of hydration processes, but sunrise is another matter. The major reason for a poor match³ of the November 1969 SPE sunrise data with time-dependent calculations using the same chemistry as here is quite likely due to the considerable hydration of negative ions that occurs unhindered by photodissociation processes at night.

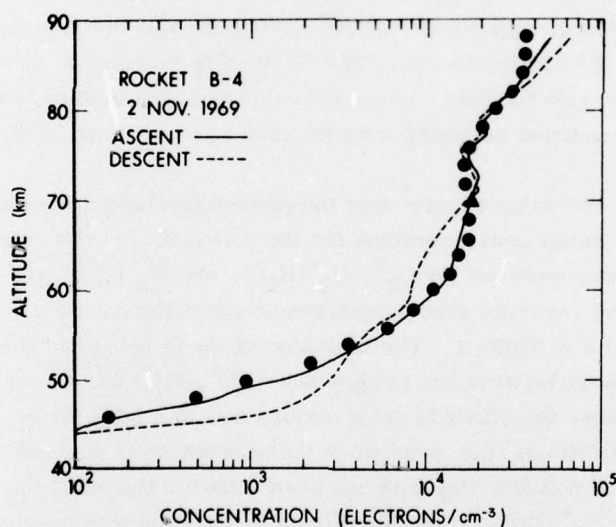


Figure 1. Measured and Computed Electron Concentrations for Rocket B-4 Launched at 2110 UT, 2 November 1969. The solar zenith angle was 83.2° . The computed electron concentrations are from Table 4

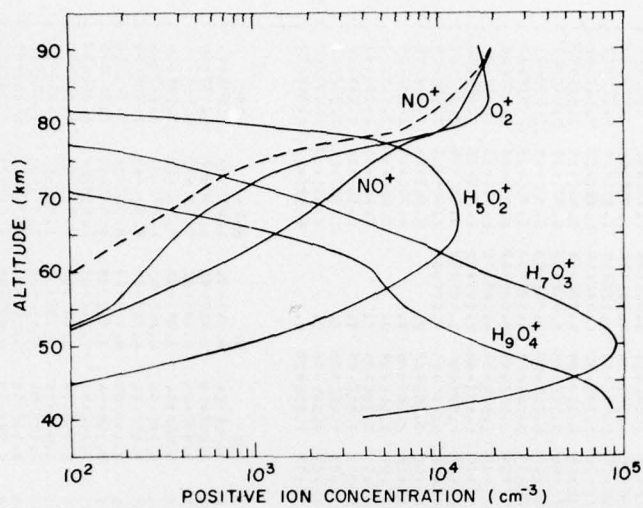


Figure 2. Principal Positive Ions Computed (Table 3) for Rocket B-4. Dashed curve from Table 4

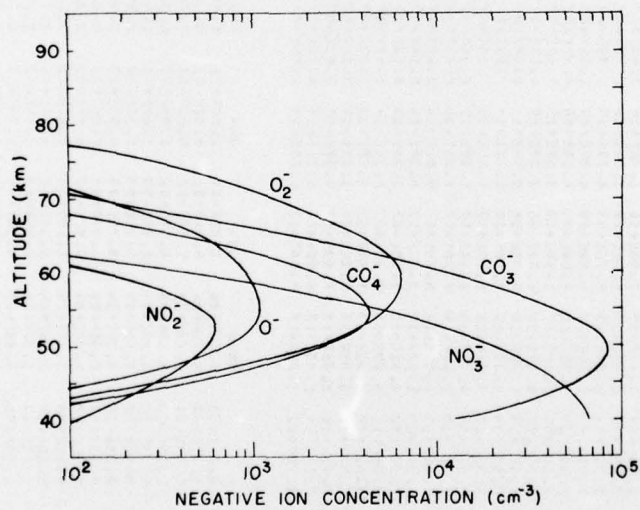


Figure 3. Principal Negative Ions Computed (Table 3) for Rocket B-4

Table 3. Complete Printout of Calculations for 2110 UT, 2 November 1969. The first three sets of altitude listings give temperature (°K) and assumed (neutral) and calculated electron and ion concentrations in units of cm^{-3} . The last set of altitude listings shows parameters described in Section 2, Outline of Model such as L(A), Eq. (2) of text, λ , and $Q/[e]^2$, where Q is the ionization production rate, $\text{cm}^{-3} \text{ sec}^{-1}$. (k_3 set to zero)

ALTITUDE	0	O2	O3	M2	M2	NO	CO2	M2O	O2(110)	NO2	M	TEMP
40.	1.00E+09	1.60E+16	4.50E+11	5.96E+16	1.00E+09	1.00E+09	2.29E+13	7.63E+10	1.00E+10	2.00E+08	7.63E+16	2.35E+02
42.	1.40E+09	1.17E+16	2.50E+11	4.37E+16	8.00E+08	1.00E+09	1.68E+13	5.60E+10	6.00E+09	6.00E+07	5.60E+16	2.41E+02
44.	1.80E+09	8.00E+15	1.50E+11	3.29E+16	5.00E+08	1.00E+09	1.26E+13	4.20E+10	1.70E+10	2.00E+07	4.20E+16	2.46E+02
46.	2.20E+09	6.40E+15	8.00E+10	2.42E+16	4.00E+08	1.00E+09	9.30E+12	3.10E+10	1.30E+10	7.00E+06	3.10E+16	2.51E+02
48.	2.50E+09	4.82E+15	5.00E+10	1.80E+16	3.20E+08	1.00E+09	6.00E+12	2.30E+10	1.30E+10	2.30E+06	2.30E+16	2.55E+02
50.	2.80E+09	3.74E+15	2.80E+10	1.39E+16	2.40E+08	1.00E+09	5.31E+12	1.77E+10	1.80E+10	8.00E+05	1.77E+16	2.58E+02
52.	3.10E+09	2.83E+15	1.50E+10	1.05E+16	1.70E+08	1.00E+09	4.05E+12	1.35E+10	1.80E+10	3.00E+05	1.35E+16	2.59E+02
54.	3.30E+09	2.20E+15	8.70E+09	8.20E+15	1.30E+08	1.00E+09	3.15E+12	1.05E+10	1.80E+10	1.10E+05	1.05E+16	2.57E+02
56.	3.50E+09	1.60E+15	5.00E+09	6.25E+15	1.00E+08	1.00E+09	2.40E+12	8.00E+09	1.10E+10	8.00E+04	8.00E+15	2.54E+02
58.	3.60E+09	1.34E+15	2.80E+09	5.00E+15	7.30E+07	1.00E+09	1.92E+12	6.40E+09	9.00E+09	1.70E+04	6.40E+15	2.50E+02
60.	3.60E+09	1.04E+15	1.60E+09	3.85E+15	5.70E+07	1.00E+09	1.49E+12	4.97E+09	9.00E+09	7.00E+03	4.97E+15	2.45E+02
62.	3.60E+09	8.17E+14	9.00E+08	3.05E+15	4.70E+07	1.00E+09	1.17E+12	3.90E+09	4.70E+09	3.20E+03	3.90E+15	2.42E+02
64.	3.50E+09	6.29E+14	5.00E+08	2.34E+15	4.00E+07	1.00E+09	9.00E+11	3.00E+09	3.00E+09	1.50E+03	3.00E+15	2.37E+02
66.	3.30E+09	4.71E+14	2.80E+08	1.75E+15	3.50E+07	1.00E+09	6.75E+11	2.25E+09	2.40E+09	8.00E+02	2.40E+15	2.33E+02
68.	3.30E+09	3.67E+14	1.70E+08	1.37E+15	3.20E+07	1.00E+09	5.25E+11	1.75E+09	1.60E+09	4.60E+02	1.75E+15	2.28E+02
70.	3.00E+09	2.74E+14	1.10E+08	1.02E+15	2.90E+07	1.00E+09	3.93E+11	1.31E+09	1.10E+09	2.50E+02	1.31E+15	2.25E+02
72.	3.00E+09	2.07E+14	7.00E+07	7.75E+14	2.70E+07	1.00E+09	2.97E+11	9.90E+08	7.00E+08	1.50E+02	9.90E+14	2.22E+02
74.	3.40E+09	1.57E+14	4.70E+07	5.65E+14	2.50E+07	1.00E+09	2.25E+11	7.50E+08	4.70E+08	9.00E+01	7.50E+14	2.19E+02
76.	4.50E+09	1.17E+14	3.30E+07	4.37E+14	2.50E+07	1.00E+09	1.68E+11	5.60E+08	3.30E+08	0.	5.60E+14	2.16E+02
78.	9.00E+09	8.00E+13	2.00E+07	3.24E+14	2.50E+07	1.00E+09	1.20E+11	4.20E+08	2.00E+08	0.	4.20E+14	2.13E+02
80.	3.00E+10	6.29E+13	2.00E+07	2.74E+14	2.70E+07	1.00E+09	9.00E+10	3.00E+08	2.00E+08	0.	3.00E+14	2.11E+02
82.	9.00E+10	4.61E+13	3.00E+07	1.72E+14	2.70E+07	1.00E+09	6.60E+10	2.20E+08	3.00E+08	0.	2.20E+14	2.10E+02
84.	1.50E+11	3.35E+13	5.00E+07	1.25E+14	3.00E+07	1.00E+09	4.80E+10	1.50E+08	5.00E+08	0.	1.50E+14	2.09E+02
86.	2.20E+11	2.51E+13	7.00E+07	9.37E+13	3.50E+07	1.00E+09	3.60E+10	1.20E+08	7.00E+08	0.	1.20E+14	2.09E+02
88.	2.70E+11	1.80E+13	9.00E+07	6.71E+13	4.50E+07	1.00E+09	2.56E+10	9.00E+08	9.00E+08	0.	9.00E+13	2.10E+02
90.	3.20E+11	1.28E+13	7.00E+07	4.78E+13	4.50E+07	1.00E+09	1.84E+10	6.12E+07	7.00E+08	0.	6.12E+13	2.11E+02

ALTITUDE	E	NSUM	O2	OM	COM	OM	CO3	O-	NO2	NO3
40.	4.65E+00	8.15E+04	1.02E+01	1.13E+01	1.96E+01	5.37E-01	1.26E+04	6.64E+00	1.95E+02	6.87E+04
42.	1.72E+01	9.06E+04	4.66E+01	3.87E-01	8.38E+01	1.13E+00	2.92E+04	2.81E+01	1.74E+02	6.10E+04
44.	5.45E+01	1.01E+05	1.59E+02	9.63E-01	2.56E+02	4.45E+00	5.03E+04	8.26E+01	2.46E+02	5.01E+04
46.	1.51E+02	1.10E+05	4.43E+02	1.96E+00	6.31E+02	8.94E+00	6.94E+04	1.97E+02	3.32E+02	3.86E+04
48.	4.34E+02	1.15E+05	1.06E+03	3.42E+00	1.35E+03	1.40E+01	8.28E+04	4.04E+02	4.37E+02	2.84E+04
50.	9.97E+02	1.11E+05	2.17E+03	5.33E+00	2.59E+02	2.06E+01	8.40E+04	6.78E+02	5.62E+02	2.05E+04
52.	2.11E+03	9.34E+04	3.70E+03	6.92E+00	3.90E+03	2.32E+01	7.14E+04	9.37E+02	6.33E+02	1.27E+04
54.	3.63E+03	6.96E+04	4.97E+03	7.26E+00	4.40E+03	2.15E+01	5.13E+04	1.07E+03	5.98E+02	7.22E+03
56.	5.97E+03	4.73E+04	5.93E+03	6.67E+00	3.86E+03	1.79E+01	3.25E+04	1.09E+03	4.63E+02	3.35E+03
58.	8.46E+03	3.17E+04	6.42E+03	5.87E+00	3.21E+03	1.31E+01	1.94E+04	1.02E+03	2.93E+02	1.27E+03
60.	1.15E+04	2.04E+04	6.19E+03	4.49E+00	2.13E+03	8.94E+00	1.06E+04	9.00E+02	1.58E+02	4.31E+02
62.	1.31E+04	1.31E+04	5.55E+03	3.13E+00	1.27E+03	5.59E+00	5.45E+03	7.80E+02	7.87E+01	1.40E+02
64.	1.60E+04	8.08E+03	4.34E+03	1.96E+00	6.37E+02	3.19E+00	2.43E+03	5.90E+02	3.34E+01	4.16E+01
66.	1.75E+04	4.55E+03	2.94E+03	1.02E+00	2.53E+02	1.60E+00	9.25E+02	4.01E+02	1.7E+01	1.40E+01
68.	1.82E+04	2.80E+03	2.04E+03	5.55E-01	1.12E+02	8.38E-01	3.57E+02	2.72E+02	4.76E+00	3.74E+00
70.	1.82E+04	1.61E+03	1.25E+03	2.61E-01	4.13E+01	4.36E-01	1.94E+02	1.59E+02	1.64E+00	1.12E+00
72.	1.75E+04	8.75E+02	7.14E+02	1.14E-01	1.37E+01	1.54E-01	5.44E+01	9.18E+01	5.26E-01	3.21E-01
74.	1.73E+04	4.61E+02	3.83E+02	4.63E-02	4.06E+00	9.77E-02	1.83E+01	5.88E+01	1.61E-01	8.77E-02
76.	1.81E+04	2.30E+02	1.89E+02	1.75E-02	9.86E-01	4.61E-02	5.50E+00	3.18E+01	4.24E-02	2.80E-02
78.	2.17E+04	9.97E+01	7.64E+01	5.38E-03	1.49E-01	2.02E-02	1.15E+00	2.20E+01	7.81E-03	2.99E-03
80.	2.89E+04	2.73E+01	1.80E+01	9.15E-04	6.94E-03	5.37E-03	8.02E-02	9.13E+00	4.97E-04	1.45E-04
82.	3.20E+04	6.15E+00	3.73E+00	1.40E-04	2.81E-04	1.47E-03	5.55E-03	2.41E+00	3.80E-05	6.77E-06
84.	3.37E+04	2.11E+00	1.25E+00	3.42E-05	3.06E-05	6.33E-04	1.12E-03	8.54E-01	6.57E-05	1.11E-06
86.	3.46E+04	8.41E-01	4.94E-01	1.01E-05	4.67E-06	3.14E-04	2.59E-04	3.46E-01	1.76E-06	2.79E-07
88.	3.53E+04	3.65E-01	2.14E-01	3.13E-06	8.43E-07	1.56E-04	7.46E-05	1.51E-01	5.45E-07	9.07E-08
90.	3.55E+04	1.59E-01	9.24E-02	9.57E-07	1.55E-07	4.70E-05	1.35E-05	6.61E-02	1.12E-07	1.56E-08

Table 3. Complete Printout of Calculations for 2110 UT, 2 November 1969 (Cont)

ALTITUDE	LA	LANDA	O/F#-2	PSUN	MSUM+E	INT. SP	SP	INT. E	E	O
42.	4.51E-02	1.75F-04	1.84E-01	8.14E-04	8.15E-04	8.15E-04	8.15E-04	6.37E+00	4.66E+00	4.00E+02
44.	2.50E-02	5.26E-03	1.69E-01	9.05E-04	9.06E-04	9.07E-04	9.08E-04	2.07E+01	1.72E+01	5.00E+02
46.	1.44E-02	1.46E-03	2.17E-01	1.01E-05	1.01E-05	1.01E-05	1.01E-05	6.55E+01	5.43E+01	6.40E+02
48.	4.04E-01	6.89E-02	3.15E-02	1.10E-05	1.10E-05	1.10E-05	1.10E-05	2.00E+02	1.59E+02	4.00E+02
50.	4.50E-01	2.66E-02	5.39E-03	1.15E-05	1.15E-05	1.15E-05	1.15E-05	6.35E+02	4.3E+02	1.00E+03
52.	2.70E-01	1.11E-02	1.21E-03	1.13E-05	1.13E-05	1.13E-05	1.13E-05	1.12E+05	9.97E+02	1.20E+03
54.	1.57E-01	4.62E-01	3.02E-04	9.43E-04	9.55E-04	1.13E-05	9.55E-04	2.82E+03	2.14E+03	1.35E+03
56.	9.63E-00	1.89E-01	1.02E-04	7.32E-04	7.32E-04	1.01E-05	7.32E-04	4.46E+03	3.69E+03	1.39E+03
58.	5.42E-00	7.92E-00	3.91E-05	5.32E-04	5.32E-04	8.96E-04	5.32E-04	5.69E+03	5.97E+03	1.79E+03
60.	3.41E-02	3.74E-00	1.89E-05	4.01E-04	4.01E-04	7.71E-04	4.01E-04	9.13E+03	8.46E+03	1.35E+03
62.	2.01E-00	1.02E-00	1.01E-05	3.17E-04	3.17E-04	6.99E-04	3.17E-04	1.22E+04	1.14E+04	1.30E+03
64.	1.22E-00	9.63E-01	6.31E-06	2.71E-04	2.71E-04	6.17E-04	2.71E-04	1.37E+04	1.30E+04	1.20E+03
66.	7.04E-01	5.04E-01	4.27E-05	2.42E-04	2.42E-04	5.64E-04	2.42E-04	1.56E+04	1.60E+04	1.10E+03
68.	3.88E-01	2.59E-01	3.12E-05	2.23E-04	2.23E-04	5.11E-04	2.23E-04	1.71E+04	1.75E+04	9.60E+02
70.	2.23E-01	1.55E-01	2.55E-05	2.05E-04	2.11E-04	4.74E-04	2.11E-04	1.80E+04	1.82E+04	8.50E+02
72.	1.26E-01	8.83E-02	2.17E-06	1.98E-04	1.98E-04	4.13E-04	1.98E-04	2.00E+04	1.82E+04	7.20E+02
74.	7.06E-02	5.00E-02	1.89E-06	1.83E-04	1.83E-04	3.58E-04	1.83E-04	2.80E+04	1.75E+04	5.80E+02
76.	3.93E-02	2.67E-02	1.64E-06	1.78E-04	1.77E-04	3.53E-04	1.77E-04	2.80E+04	1.73E+04	4.90E+02
78.	1.23E-02	1.27E-02	1.34E-06	1.82E-04	1.84E-04	3.38E-04	1.84E-04	2.24E+04	1.81E+04	4.40E+02
80.	6.05E-03	9.43E-04	5.03E-07	2.88E-04	2.10E-04	3.26E-04	2.88E-04	2.58E+04	2.17E+04	4.25E+02
82.	3.23E-03	1.92E-04	4.30E-07	3.21E-04	3.20E-04	3.32E-04	3.32E-04	2.58E+04	2.89E+04	4.20E+02
84.	1.70E-03	6.25E-05	4.22E-07	3.37E-04	3.37E-04	3.46E-04	3.37E-04	3.20E+04	3.28E+04	4.80E+02
86.	9.55E-04	2.43E-05	4.27E-07	3.42E-04	3.46E-04	3.57E-04	3.46E-04	3.57E+04	3.46E+04	5.10E+02
88.	4.94E-04	1.03E-05	4.31E-07	3.53E-04	3.54E-04	3.67E-04	3.54E-04	4.11E+04	3.54E+04	5.40E+02
90.	2.82E-04	4.46E-05	4.35E-07	3.53E-04	3.55E-04	3.71E-04	3.55E-04	4.26E+04	3.55E+04	5.50E+02

Table 4. Same as for Table 3 Except k₄₃ as in Table 1. The first set of altitude listings is omitted since it is the same as for Table 3

ALTITUDE	E	MSUM	02-	04-	CO4-	03-	CO3-	0-	NO2-	NO3-
40.	4.66E+00	9.15E+04	1.02E+01	1.18E-01	1.96E+01	5.37E-01	1.26E+04	6.64E+00	1.05E+02	6.87E+04
42.	1.72E+01	9.06E+04	4.64E+01	3.87E-01	8.30E+01	1.83E+00	2.92E+04	2.81E+01	1.74E+02	6.10E+04
44.	5.43E+01	1.01E+05	1.50E+02	9.63E-01	2.56E+02	4.55E+00	5.03E+04	8.26E+01	3.32E+02	5.01E+04
46.	1.53E+02	1.10E+05	4.43E+02	1.95E+00	6.31E+02	8.91E+00	6.94E+04	1.97E+02	3.32E+02	3.66E+04
48.	4.31E+02	1.15E+05	1.06E+03	3.62E+00	1.35E+03	1.44E+01	8.28E+04	4.04E+02	4.37E+02	2.84E+04
50.	9.97E+02	1.11E+05	2.17E+03	5.33E+00	2.59E+03	2.06E+01	8.40E+04	6.77E+02	5.62E+02	2.05E+04
52.	2.11E+03	9.34E+04	3.70E+03	6.92E+00	3.90E+03	2.32E+01	7.14E+04	9.56E+02	6.33E+02	1.27E+04
54.	3.63E+03	6.96E+04	4.97E+03	7.25E+00	4.39E+03	2.15E+01	5.13E+04	1.07E+03	5.97E+02	7.22E+03
56.	5.93E+03	4.72E+04	5.97E+03	6.64E+00	3.06E+03	1.79E+01	3.25E+04	1.00E+03	4.61E+02	3.35E+03
58.	8.44E+03	3.16E+04	6.40E+03	5.05E+00	3.20E+03	1.30E+01	1.94E+04	1.01E+03	2.92E+02	1.27E+03
60.	1.13E+04	2.09E+04	6.15E+03	3.43E+00	2.41E+03	8.39E+00	1.08E+04	8.98E+02	1.57E+02	4.28E+02
62.	1.37E+04	1.32E+04	5.50E+03	3.17E+00	1.26E+03	5.39E+00	5.38E+03	7.72E+02	7.22E+01	1.28E+02
64.	1.58E+04	7.95E+03	4.28E+03	1.93E+00	6.27E+02	3.18E+00	2.39E+03	5.84E+02	3.29E+01	4.08E+01
66.	1.73E+04	4.42E+03	2.86E+03	9.87E-01	2.46E+02	1.56E+00	8.97E+02	3.89E+02	1.08E+01	1.02E+01
68.	1.75E+04	2.71E+03	1.95E+03	5.35E-01	1.08E+02	8.24E-01	3.84E+02	2.61E+02	4.57E+00	3.59E+00
70.	1.73E+04	1.53E+03	1.13E+03	2.47E-01	3.92E+01	4.14E-01	1.46E+02	1.51E+02	1.56E+00	1.07E+00
72.	1.64E+04	8.18E+02	6.64E+02	1.06E-01	1.28E+01	1.32E-01	5.08E+01	8.58E+01	4.92E-01	1.48E-01
74.	1.53E+04	4.24E+02	3.52E+02	4.31E-02	3.73E+00	8.99E-02	1.68E+01	3.32E+01	3.80E-02	1.80E-02
76.	1.62E+04	2.05E+02	1.69E+02	1.57E-02	8.04E-01	4.13E-02	4.92E+00	1.94E+01	6.92E-03	2.65E-03
78.	1.92E+04	8.81E+01	6.75E+01	4.75E-03	1.32E-01	1.73E-02	1.02E+00	1.94E+01	6.92E-03	2.65E-03
80.	2.66E+04	2.51E+01	1.66E+01	8.43E-04	6.39E-03	4.94E-03	7.38E-02	8.41E+00	4.59E-04	1.33E-04
82.	3.06E+04	5.87E+00	3.56E+00	1.33E-04	2.60E-04	1.41E-03	5.30E-03	2.30E+00	3.04E-05	6.49E-06
84.	3.28E+04	2.05E+00	1.25E+00	3.35E-05	2.97E-05	6.74E-04	1.03E-03	8.30E-01	6.40E-06	1.08E-06
86.	3.60E+04	8.27E-01	4.86E-01	9.93E-06	4.59E-06	3.03E-04	2.55E-04	3.44E-01	1.68E-06	2.75E-07
88.	3.52E+04	3.62E-01	2.12E-01	3.16E-06	8.36E-07	1.55E-04	7.46E-05	1.50E-01	5.44E-07	9.00E-08
90.	3.43E+04	1.58E-01	9.28E-02	9.53E-07	1.55E-07	4.83E-05	1.35E-05	6.58E-02	1.11E-07	1.56E-08

ALTITUDE	02+	04+	02+M20	M30+	M30+-J4	M30+-M2	M30+-CO2	M502+	M50+-202	NO+	NO+-M2
40.	1.35E-01	3.17E+00	3.91E+00	2.81E+00	2.81E+00	2.61E-03	7.89E+00	1.13E+01	7.74E+00	9.71E-02	7.31E-04
42.	4.89E-01	5.40E+00	6.69E+00	4.79E+00	4.79E+00	4.45E-03	1.35E+01	2.79E+01	1.49E+01	2.70E-01	1.22E-03
44.	1.59E+00	1.57E+01	1.86E+01	1.38E+01	1.38E+01	7.57E-03	2.27E+01	6.88E+01	2.52E+01	7.80E-01	2.06E-03
46.	5.23E+00	1.57E+01	1.93E+01	1.38E+01	1.38E+01	1.28E-02	6.45E+01	1.60E+02	4.46E+01	1.87E+00	5.33E-03
48.	1.57E+01	2.66E+01	3.25E+01	2.32E+01	2.32E+01	2.16E-02	6.45E+01	3.77E+02	7.77E+01	4.75E+00	5.64E-03
50.	3.94E+01	4.16E+01	5.04E+01	3.61E+01	3.61E+01	3.36E-02	1.00E+02	7.81E+02	1.24E+02	1.05E+01	8.75E-03
52.	7.67E+01	6.19E+01	7.45E+01	5.33E+01	5.33E+01	4.94E-02	1.47E+02	1.50E+03	1.80E+02	2.04E+01	1.30E-02
54.	1.23E+02	8.26E+01	9.85E+01	7.03E+01	7.03E+01	6.53E-02	1.94E+02	2.49E+03	2.32E+02	3.42E+01	1.74E-02
56.	1.75E+02	1.10E+02	1.23E+02	9.21E+01	9.21E+01	8.53E-02	2.52E+02	4.05E+03	2.84E+02	5.49E+01	2.34E-02
58.	2.85E+02	1.35E+02	1.57E+02	1.12E+02	1.12E+02	1.04E-01	3.03E+02	5.65E+03	3.11E+02	7.46E+01	2.87E-02
60.	2.37E+02	1.71E+02	1.94E+02	1.38E+02	1.38E+02	1.24E-01	3.67E+02	7.83E+03	3.26E+02	1.84E+02	3.64E-02
62.	2.93E+02	2.05E+02	2.27E+02	1.61E+02	1.61E+02	1.50E-01	4.20E+02	9.80E+03	3.11E+02	1.43E+02	4.35E-02
64.	3.44E+02	2.52E+02	2.64E+02	1.90E+02	1.90E+02	1.73E-01	4.81E+02	1.15E+04	2.71E+02	1.91E+02	5.29E-02
66.	4.33E+02	3.05E+02	3.09E+02	2.15E+02	2.15E+02	2.06E-01	5.32E+02	1.29E+04	2.11E+02	2.64E+02	6.29E-02
68.	5.13E+02	3.62E+02	3.48E+02	2.45E+02	2.45E+02	2.30E-01	5.73E+02	1.32E+04	1.57E+02	3.30E+02	7.33E-02
70.	7.23E+02	4.35E+02	3.86E+02	2.71E+02	2.71E+02	2.56E-01	6.03E+02	1.27E+04	1.04E+02	4.61E+02	8.56E-02
72.	1.80E+03	4.91E+02	4.01E+02	2.80E+02	2.80E+02	2.63E-01	5.92E+02	1.13E+04	6.67E+01	6.11E+02	9.61E-02
74.	1.57E+03	5.81E+02	4.28E+02	2.96E+02	2.96E+02	2.76E-01	5.82E+02	1.13E+04	6.83E+01	6.81E+02	1.15E-01
76.	2.99E+03	7.16E+02	4.62E+02	3.17E+02	3.17E+02	2.79E-01	5.84E+02	8.11E+03	2.12E+01	1.52E+03	1.71E-01
78.	7.48E+03	7.79E+02	4.30E+02	2.83E+02	2.83E+02	2.58E-01	5.28E+02	4.11E+03	7.27E+00	3.32E+03	3.14E-01
80.	1.53E+04	3.44E+02	1.55E+02	9.81E+01	9.81E+01	8.76E-02	9.47E+01	8.19E+02	5.76E-01	7.40E+03	5.48E-01
82.	1.83E+04	8.14E+01	2.90E+01	1.73E+01	1.73E+01	1.41E-02	1.12E+01	1.00E+02	3.30E-02	1.04E+04	5.83E-01
84.	1.87E+04	3.12E+01	7.61E+00	4.21E+00	4.21E+00	2.32E-03	1.72E+00	1.47E+01	1.47E-03	1.29E+04	5.47E-01
86.	1.80E+04	1.61E+01	2.23E+00	1.14E+00	1.14E+00	6.33E-04	2.85E-01	2.86E+00	3.07E-04	1.52E+04	4.82E-01
88.	1.73E+04	4.02E+00	6.71E-01	3.03E-01	3.03E-01	1.20E-04	3.92E-02	5.24E-01	2.89E-05	1.72E+04	3.76E-01
90.	1.63E+04	1.60E+00	1.97E-01	7.71E-02	7.71E-02	2.03E-05	4.83E-03	9.33E-02	2.65E-06	1.66E+04	2.74E-01

Table 4. Same as for Table 3 Except k_{43} as in Table 1 (Cont)

ALTITUDE	NO+J22	NO+J20	NO+J20-N2	NO+J23-C02	NO+J2420	NO+J2420N2	NO+J2420C02	NO+J2420	W703+	W904+
40.	1.05E+00	1.91E-02	8.68E-04	2.61E-21	1.91E-02	8.55E-04	2.60E-01	7.49E+00	3.71E+03	7.77E+04
42.	1.79E+00	4.97E-02	1.48E-03	4.45E-21	4.97E-02	1.48E-03	4.43E-01	1.28E+01	1.26E+04	7.79E+04
44.	3.07E+00	1.24E-01	2.54E-03	7.61E-21	1.24E-01	2.53E-03	7.58E-01	2.19E+01	3.11E+04	7.01E+04
46.	5.22E+00	3.13E-01	4.32E-03	1.30E-20	3.12E-01	4.31E-03	1.29E+00	3.72E+01	5.96E+04	4.98E+04
48.	8.80E+00	7.69E-01	7.35E-03	2.20E-20	7.65E-01	7.12E-03	2.20E+00	6.31E+01	8.38E+04	3.04E+04
50.	1.40E+01	1.66E+00	1.16E-02	3.48E-20	1.65E+00	1.16E-02	3.46E+00	9.92E+01	9.27E+04	1.75E+04
52.	2.00E+01	3.23E+00	1.72E-02	5.15E-20	3.22E+00	1.72E-02	5.14E+00	1.46E+02	8.09E+04	1.17E+04
54.	2.70E+01	5.45E+00	2.30E-02	6.88E-20	5.42E+00	2.28E-02	6.85E+00	1.92E+02	6.17E+04	7.95E+03
56.	3.65E+01	8.91E+00	3.02E-02	9.05E-20	8.88E+00	3.00E-02	8.99E+00	2.47E+02	4.17E+04	5.92E+03
58.	4.95E+01	1.25E+01	3.63E-02	1.09E-21	1.24E+01	3.60E-02	1.08E+01	2.86E+02	2.75E+04	5.16E+03
60.	6.65E+01	1.81E+01	4.46E-02	1.33E-21	1.79E+01	4.41E-02	1.32E+01	3.31E+02	1.72E+04	3.08E+03
62.	8.35E+01	2.59E+01	5.23E-02	1.55E-21	2.52E+01	5.14E-02	1.53E+01	3.60E+02	1.44E+04	2.08E+03
64.	1.05E+02	3.59E+01	6.17E-02	1.84E-21	3.49E+01	6.11E-02	1.78E+01	3.94E+02	7.56E+03	2.08E+03
66.	1.30E+02	5.13E+01	7.13E-02	2.11E-21	4.92E+01	6.94E-02	2.02E+01	3.91E+02	3.28E+03	5.34E+02
68.	1.55E+02	6.74E+01	8.02E-02	2.37E-21	6.35E+01	7.56E-02	2.22E+01	3.90E+02	3.28E+03	5.34E+02
70.	1.80E+02	8.39E+01	9.05E-02	2.65E-21	8.76E+01	8.27E-02	2.41E+01	3.76E+02	2.08E+03	5.22E+01
72.	2.05E+02	1.09E+02	9.78E-02	2.85E-21	1.13E+02	8.58E-02	2.48E+01	3.47E+02	1.59E+03	5.22E+01
74.	2.30E+02	1.34E+02	1.14E-01	3.31E-21	1.54E+02	9.78E-02	2.69E+01	3.29E+02	7.80E+02	3.22E+01
76.	2.55E+02	1.59E+02	1.31E-01	4.34E-21	2.30E+02	1.11E-01	3.13E+01	3.16E+02	4.28E+02	1.01E+01
78.	2.80E+02	1.84E+02	1.48E-01	5.55E-21	3.57E+02	1.37E-01	3.74E+01	2.75E+02	1.74E+02	2.85E+00
80.	3.05E+02	2.09E+02	1.65E-01	6.55E-21	5.24E+02	1.57E-01	4.24E+01	1.00E+02	2.42E+01	1.08E+01
82.	3.30E+02	2.34E+02	1.82E-01	7.05E-21	7.05E+02	1.71E-01	4.70E+01	2.25E+01	3.06E+00	6.50E-03
84.	3.55E+02	2.59E+02	1.99E-01	7.55E-21	9.16E+02	1.91E-01	5.16E+01	3.61E+00	3.44E+01	3.65E-04
86.	3.80E+02	2.84E+02	2.16E-01	8.05E-21	1.12E+03	2.16E-01	5.62E+01	6.27E-01	4.07E-02	2.55E-05
88.	4.05E+02	3.09E+02	2.33E-01	8.55E-21	1.33E+03	2.33E-01	6.07E+01	4.37E-03	2.58E-03	7.56E-07
90.	4.30E+02	3.34E+02	2.50E-01	9.05E-21	1.54E+03	2.50E-01	6.45E+01	4.37E-03	1.57E-04	2.20E-08

4. NUMERICAL EXAMPLE: Nighttime

Table 5 contains charged particle concentrations appropriate to SPE conditions during the night of 3 November 1969 at Ft. Churchill, Canada. The ionization production rates, principal constituents, and temperatures are identical to those used in our report¹ dealing with a model for the nighttime steady-state disturbed D-region. Our current, more advanced model results are not extremely different in regards to [e] as compared to our previous effort. The major difference, a somewhat lower [e] now in the 80-65 km region is actually in better accord with the data. The results in Table 5 were obtained with $k_{43} \neq 0$. Uncertainties in the NO^+ chemistry and the chosen NO profile notwithstanding, it still is worthwhile to point out that the calculations accomplished with the Table 1 value for k_{43} resulted in an NO^+ concentration at 70 km of $2 \times 10^2 \text{ cm}^{-3}$, far below the value in Table 5 which is in good agreement with the data.² The major positive ions are plotted in Figure 4. Below about 60-65 km, the positive ions are in thermodynamic equilibrium.

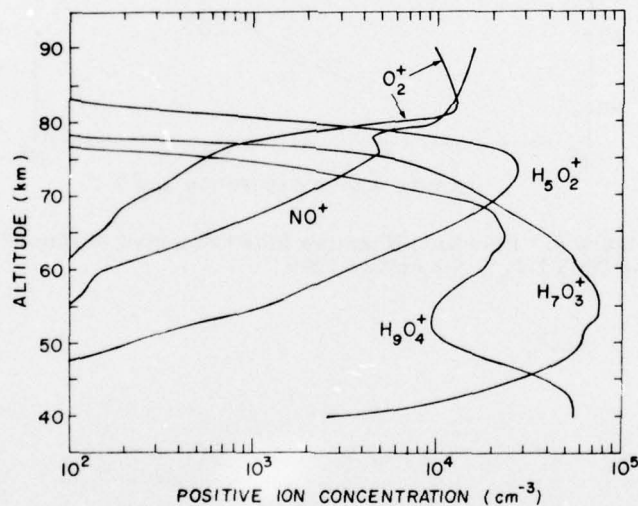


Figure 4. Principal Positive Ions Computed (Table 5) for 0605 UT, 3 November 1969, the Time of Launch for Black Brant Rocket 17.758

The negative ion populations (Figure 5) are, undoubtedly, as noted earlier, subject to considerable hydration at night. This possibility has little impact on $[e]$ unless the hydrated negative ions have much different ion-ion recombination rates with oxonium ions than do the parent, unhydrated ions. The little experimental evidence in this regard does not favor this possibility which is attested to by the rather good agreement attained between model and data for $[e]$.

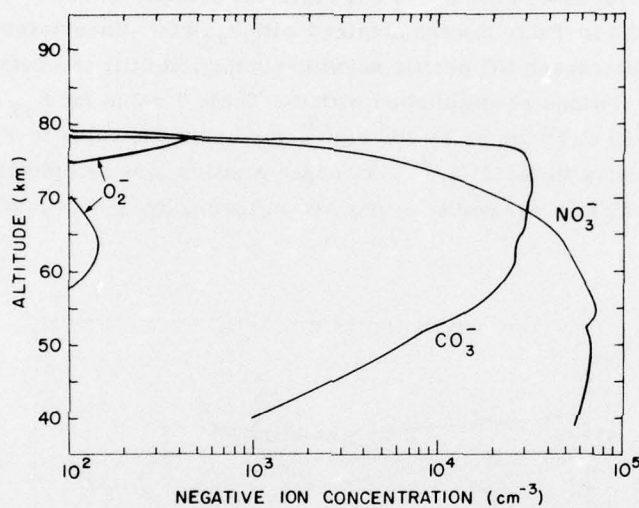


Figure 5. Principal Negative Ions Computed (Table 5) for 0605 UT, 3 November 1969

Table 5. Complete Printout of Calculations for 0605 UT, 3 November 1969. See Table 3 caption for further description of the table. Rate coefficient k_{43} was set to zero

ALTITUDE	0	02	03	M2	M0	C02	M20	02(10)	N02	M	TEMP
40.	1.00E+00	1.60E+16	4.50E+11	5.96E+16	2.00E+00	2.29E+13	7.63E+10	0.	1.00E+09	7.63E+16	2.95E+02
42.	1.60E+00	1.17E+16	2.50E+11	4.37E+16	9.00E+00	1.68E+13	5.20E+10	0.	9.00E+08	5.20E+10	2.41E+02
44.	2.50E+00	8.00E+15	1.50E+11	3.23E+16	4.00E+00	1.16E+13	4.20E+10	0.	6.00E+08	4.20E+10	2.06E+02
46.	3.90E+00	4.90E+15	8.00E+10	2.42E+16	2.00E+00	6.30E+12	3.10E+10	0.	4.00E+08	3.10E+10	2.51E+02
48.	6.10E+00	3.00E+15	5.00E+10	1.59E+16	1.00E+00	3.90E+12	2.30E+10	0.	3.20E+08	2.30E+10	2.55E+02
50.	1.00E+01	1.71E+15	3.10E+10	1.39E+16	5.00E+00	5.31E+12	1.77E+10	0.	2.60E+08	1.77E+10	2.58E+02
52.	1.50E+01	8.33E+14	2.20E+10	1.05E+16	2.00E+00	3.55E+12	1.35E+10	0.	1.70E+08	1.35E+10	2.58E+02
54.	2.00E+01	4.20E+14	1.30E+10	8.20E+15	3.00E+00	3.15E+12	1.05E+10	0.	1.30E+08	1.05E+10	2.57E+02
56.	3.75E+01	1.68E+14	9.00E+09	6.25E+15	3.00E+00	3.55E+12	9.00E+09	0.	1.00E+08	9.00E+09	2.54E+02
58.	6.10E+01	1.30E+14	6.00E+09	5.00E+15	7.00E+00	1.92E+12	6.90E+09	0.	7.30E+07	6.90E+09	2.50E+02
60.	1.00E+02	1.00E+14	5.20E+09	3.85E+15	1.70E+00	1.92E+12	6.90E+09	0.	5.70E+07	6.90E+09	2.45E+02
62.	2.40E+02	6.17E+13	4.80E+09	3.05E+15	9.00E+00	1.72E+12	3.90E+09	0.	4.70E+07	3.90E+09	2.42E+02
64.	6.20E+02	2.99E+13	4.30E+09	2.35E+15	7.00E+00	9.00E+11	3.00E+09	0.	4.00E+07	3.00E+09	2.37E+02
66.	2.10E+03	6.71E+13	4.10E+09	1.75E+15	1.30E+00	6.75E+11	2.25E+09	0.	2.60E+07	2.25E+09	2.35E+02
68.	1.00E+04	3.67E+13	3.70E+09	1.37E+15	1.80E+00	5.25E+11	1.75E+09	0.	1.80E+07	1.75E+09	2.28E+02
70.	3.00E+04	2.76E+13	3.30E+09	1.02E+15	2.20E+00	3.35E+11	1.31E+09	0.	1.00E+07	1.31E+09	2.25E+02
72.	3.00E+05	2.07E+13	3.00E+09	7.73E+14	2.60E+00	2.97E+11	9.90E+08	0.	5.00E+06	9.90E+08	2.22E+02
74.	3.00E+06	1.57E+13	2.90E+09	5.65E+14	2.60E+00	2.25E+11	7.50E+08	0.	2.00E+06	7.50E+08	2.19E+02
76.	6.00E+07	1.17E+13	2.50E+09	4.37E+14	2.50E+00	1.68E+11	5.50E+08	0.	3.00E+05	5.50E+08	2.16E+02
78.	1.50E+09	8.00E+13	8.00E+08	3.23E+14	2.50E+00	1.26E+11	4.20E+08	0.	3.00E+04	4.20E+08	2.13E+02
80.	1.80E+10	6.29E+13	2.00E+07	2.34E+14	2.60E+00	9.00E+10	3.00E+08	0.	1.00E+02	3.00E+08	2.11E+02
82.	9.00E+10	4.61E+13	3.00E+07	1.72E+14	2.70E+00	6.00E+10	2.20E+08	0.	0.	2.20E+08	2.10E+02
84.	1.50E+11	3.35E+13	5.00E+07	1.25E+14	3.00E+00	4.00E+10	1.50E+08	0.	0.	1.50E+08	2.09E+02
86.	2.20E+11	2.51E+13	7.00E+07	3.37E+14	3.50E+00	3.60E+10	1.20E+08	0.	0.	1.20E+08	2.09E+02
88.	2.70E+11	1.80E+13	5.00E+07	6.71E+13	4.00E+00	2.80E+10	6.50E+07	0.	0.	6.50E+07	2.10E+02
90.	3.20E+11	1.28E+13	7.00E+07	4.75E+13	4.50E+00	1.84E+10	6.12E+07	0.	0.	6.12E+07	2.11E+02

ALTITUDE	E	NSUM	02-	04-	C04-	01-	02-	C03-	0-	N02-	N03-
40.	4.25E-01	5.63E+04	5.60E-01	6.50E-03	1.09E+00	1.51E-02	9.34E+02	9.34E+02	1.11E-13	5.07E-10	5.53E+04
42.	9.13E-01	6.19E+04	1.24E+00	1.03E-02	2.29E+00	2.91E-02	1.40E+03	1.40E+03	7.31E-13	6.18E-09	6.05E+04
44.	1.73E+00	6.85E+04	2.39E+00	1.46E-02	4.05E+00	3.72E-02	2.00E+03	2.00E+03	3.80E-12	6.78E-08	6.35E+04
46.	3.43E+00	6.85E+04	4.54E+00	2.00E-02	7.00E+00	5.47E-02	3.04E+03	3.04E+03	2.00E-11	8.44E-07	6.53E+04
48.	6.66E+00	7.07E+04	8.68E+00	2.80E-02	1.28E+01	7.30E-02	4.39E+03	4.39E+03	1.07E-10	1.07E-05	6.53E+04
50.	1.17E+01	7.26E+04	1.50E+01	3.68E-02	2.08E+01	1.04E-01	6.84E+03	6.84E+03	5.01E-10	1.19E-04	6.65E+04
52.	1.99E+01	7.20E+04	2.10E+01	4.08E-02	2.44E+01	1.40E-01	8.11E+03	8.11E+03	1.66E-09	9.00E-04	6.38E+04
54.	4.57E+01	8.44E+04	5.10E+01	7.44E-02	5.94E+01	2.49E-01	1.39E+04	1.39E+04	1.04E-08	1.17E-02	7.08E+04
56.	8.23E+01	8.64E+04	7.92E+01	8.91E-02	7.83E+01	3.19E-01	2.16E+04	2.16E+04	3.05E-08	7.20E-02	6.95E+04
58.	1.25E+02	8.45E+04	1.05E+02	9.60E-02	9.18E+01	4.02E-01	2.62E+04	2.62E+04	1.17E-07	2.78E-01	6.55E+04
60.	1.92E+02	8.08E+04	1.23E+02	9.32E-02	8.78E+01	4.80E-01	2.62E+04	2.62E+04	9.67E-07	2.55E+00	5.65E+04
62.	3.05E+02	7.82E+04	1.53E+02	7.95E-02	6.36E+01	5.76E-01	2.61E+04	2.61E+04	3.10E-06	5.23E+00	4.72E+04
64.	7.75E+02	7.38E+04	1.45E+02	6.54E-02	4.49E+01	6.79E-01	2.66E+04	2.66E+04	3.10E-05	5.23E+00	4.72E+04
66.	1.15E+02	6.79E+04	1.23E+02	4.46E-02	2.41E+01	7.49E-01	2.94E+04	2.94E+04	1.04E-05	1.13E+01	3.83E+04
68.	9.73E+02	6.09E+04	1.17E+02	3.20E-02	1.49E+01	7.73E-01	2.98E+04	2.98E+04	5.07E-05	1.75E+01	3.06E+04
70.	1.33E+03	5.32E+04	1.04E+02	2.16E-02	8.41E+00	8.30E-01	3.15E+04	3.15E+04	1.95E-04	2.54E+01	2.15E+04
72.	1.83E+03	4.61E+04	8.84E+01	1.41E-02	4.57E+00	8.23E-01	3.20E+04	3.20E+04	1.47E-03	3.10E+01	1.39E+04
74.	2.59E+03	3.96E+04	7.61E+01	9.31E-03	2.36E+00	8.39E-01	3.12E+04	3.12E+04	1.32E-02	3.88E+01	8.34E+03
76.	3.44E+03	3.28E+04	2.05E+02	1.91E-02	4.09E+00	2.42E+00	2.84E+04	2.84E+04	8.31E-01	3.33E+01	4.22E+03
78.	1.33E+04	2.27E+03	4.51E+02	3.18E-02	5.20E+00	3.12E+00	1.31E+03	1.31E+03	9.98E+01	4.92E+00	3.95E+02
80.	2.00E+04	3.96E+01	2.25E+01	1.14E-03	1.63E-02	8.61E-03	2.37E-01	2.37E-01	1.68E+01	2.26E-02	5.07E-02
82.	2.43E+04	5.22E+00	2.98E+00	1.12E-04	2.35E-04	1.25E-03	4.92E-03	4.92E-03	2.23E+00	3.48E-04	8.32E-04
84.	2.51E+04	1.68E+00	9.60E-01	2.63E-05	2.41E-05	5.53E-04	9.17E-04	9.17E-04	7.19E-01	5.02E-05	1.71E-04
86.	2.54E+04	6.43E-01	3.64E-01	7.54E-06	3.54E-06	2.01E-04	2.61E-04	2.61E-04	2.75E-01	9.69E-06	4.44E-05
88.	2.51E+04	2.70E-01	1.54E-01	2.26E-06	6.18E-07	1.15E-04	5.59E-05	5.59E-05	1.16E-01	2.56E-06	1.44E-05
90.	2.51E+04	1.15E-01	6.58E-02	6.82E-07	1.12E-07	3.41E-05	9.33E-06	9.33E-06	4.93E-02	6.30E-07	2.80E-06

Table 5. Complete Printout of Calculations for 0605 UT, 3 November 1969 (Cont)

ALTITUDE	02+	04+	02+M20	M30+JH	M30+	M30+N2	M30+CO2	M502+	M50+J02	N0+
40.	6.51E-02	1.45E+00	1.87E+00	1.33E+00	3.58E-03	1.27E-03	3.71E+00	5.02E+00	3.68E+00	2.85E-01
42.	2.23E-01	2.46E+00	3.08E+00	2.20E+00	6.28E-03	2.00E-03	6.12E+00	1.28E+01	6.46E+00	6.73E-01
44.	6.33E-01	3.69E+00	4.61E+00	3.29E+00	1.72E-02	3.00E-03	9.16E+00	2.69E+01	1.02E+01	1.40E+00
46.	1.73E+00	5.42E+00	6.77E+00	4.84E+00	3.57E-02	6.49E-03	1.94E+01	5.62E+01	1.57E+01	2.90E+00
48.	4.62E+00	7.82E+00	9.78E+00	6.98E+00	7.16E-02	1.49E-02	3.94E+01	1.18E+02	2.35E+01	5.63E+00
50.	1.02E+01	1.06E+01	1.36E+01	9.64E+00	1.32E-01	4.39E-03	2.69E+01	2.10E+02	3.34E+01	1.07E+01
52.	1.74E+01	1.41E+01	1.76E+01	1.25E+01	2.25E-01	1.17E-02	3.49E+01	3.57E+02	4.32E+01	1.63E+01
54.	3.79E+01	2.56E+01	3.20E+01	2.24E+01	5.21E-01	2.91E-02	8.64E+01	8.21E+02	7.72E+01	4.22E+01
56.	5.67E+01	3.59E+01	4.47E+01	3.19E+01	9.35E-01	3.54E-02	1.06E+02	1.45E+03	1.04E+02	7.56E+01
58.	6.54E+01	4.39E+01	5.43E+01	3.92E+01	1.39E+00	5.59E-02	1.36E+02	2.24E+03	1.21E+02	1.12E+02
60.	7.43E+01	5.54E+01	6.92E+01	4.94E+01	2.17E+00	8.39E-02	1.76E+02	3.05E+03	1.43E+02	1.74E+02
62.	8.31E+01	6.74E+01	8.19E+01	5.84E+01	3.49E+00	5.35E-02	2.31E+02	5.06E+03	1.75E+02	2.78E+02
64.	1.00E+02	7.14E+01	9.15E+01	6.43E+01	5.73E+00	7.85E-02	2.71E+02	7.90E+03	2.09E+02	4.52E+02
66.	1.24E+02	9.47E+01	1.15E+02	8.43E+01	9.69E+00	1.03E-01	3.01E+02	1.23E+04	2.42E+02	7.54E+02
68.	1.60E+02	1.24E+02	1.55E+02	1.11E+02	1.43E+01	1.25E-01	3.64E+02	1.86E+04	2.52E+02	1.71E+03
70.	1.90E+02	1.50E+02	1.85E+02	1.35E+02	1.83E+01	1.57E-01	4.49E+02	2.64E+04	2.49E+02	2.57E+03
72.	3.35E+02	2.29E+02	3.49E+02	2.03E+02	3.66E+01	2.78E-01	5.30E+02	2.70E+04	2.14E+02	3.65E+03
74.	4.52E+02	2.76E+02	4.12E+02	2.43E+02	5.64E+01	4.20E-01	6.16E+02	2.81E+04	1.61E+02	4.88E+03
76.	6.36E+02	3.34E+02	4.12E+02	2.91E+02	8.00E+01	2.70E-01	7.00E+02	2.44E+04	9.98E+01	4.44E+03
78.	1.27E+03	3.69E+02	4.61E+02	3.13E+02	1.24E+02	2.93E-01	5.37E+02	7.44E+03	1.39E+01	9.03E+03
80.	7.31E+03	2.73E+02	2.08E+02	1.05E+02	1.05E+02	1.91E-01	2.32E+02	2.24E+03	1.92E+00	1.21E+04
82.	1.24E+04	5.60E+01	5.89E+01	3.63E+01	2.36E+01	3.02E-02	2.77E+01	2.35E+02	1.01E-01	9.03E+03
84.	1.21E+04	1.80E+01	1.78E+01	1.04E+01	8.06E+00	7.55E-03	5.42E+00	4.72E+01	1.12E-02	1.30E+04
86.	1.13E+04	6.36E+00	5.87E+00	3.22E+00	2.77E+00	1.93E-03	1.12E+00	1.09E+01	1.52E-03	1.40E+04
88.	1.01E+04	2.41E+00	2.02E+00	1.01E+00	9.07E-01	4.52E-04	1.97E-01	2.44E+00	1.82E-04	1.47E+04
90.	9.53E+03	9.35E-01	6.94E-01	3.11E-01	2.69E-01	9.45E-05	3.00E-02	5.38E-01	2.10E-05	1.55E+04
ALTITUDE	N0+J20	N0+J20	N0+J20	N0+J20	N0+J20	N0+J20	N0+J20	N0+J20	N0+J20	N0+J20
40.	4.94E-01	9.07E-03	1.28E-01	1.28E-01	3.08E-03	4.12E-04	1.23E-01	3.55E+00	2.56E+03	4.90E+04
42.	4.21E-01	2.28E-02	6.78E-04	2.05E-01	2.22E-03	6.77E-04	1.23E-01	3.55E+00	2.56E+03	5.37E+04
44.	1.21E+00	4.97E-02	1.02E-03	3.05E-01	4.98E-02	1.02E-03	3.04E-01	8.76E+00	8.57E+03	4.53E+04
46.	1.81E+00	1.06E-01	1.43E-03	4.43E-01	1.08E-02	1.43E-03	4.46E-01	1.29E+01	3.70E+04	3.09E+04
48.	2.61E+00	2.26E-01	2.16E-03	6.47E-01	2.25E-01	2.16E-03	6.44E-01	1.96E+01	5.13E+04	1.67E+04
50.	3.61E+00	4.27E-01	2.99E-03	8.95E-01	4.26E-01	2.97E-03	8.92E-01	2.57E+01	6.08E+04	1.15E+04
52.	4.68E+00	7.27E-01	3.87E-03	1.15E+00	7.24E-01	3.96E-03	1.16E+00	3.33E+01	6.24E+04	9.03E+03
54.	6.65E+00	1.66E+00	7.02E-03	2.10E+00	1.66E+00	6.98E-03	2.10E+00	6.01E+01	7.42E+04	9.49E+03
56.	1.19E+01	2.89E+00	9.79E-03	2.94E+00	2.89E+00	9.75E-03	2.92E+00	8.36E+01	7.39E+04	1.06E+04
58.	1.45E+01	4.12E+00	1.27E-02	3.59E+00	4.10E+00	1.19E-02	3.57E+00	1.02E+02	6.82E+04	1.34E+04
60.	1.82E+01	6.09E+00	1.50E-02	4.50E+00	6.07E+00	1.43E-02	4.48E+00	1.27E+02	5.92E+04	1.60E+04
62.	2.33E+01	9.43E+00	1.91E-02	5.74E+00	9.44E+00	1.33E-02	5.75E+00	1.62E+02	5.13E+04	1.93E+04
64.	3.04E+01	1.46E+01	2.51E-02	7.52E+00	1.45E+01	1.33E-02	7.46E+00	2.09E+02	4.19E+04	2.31E+04
66.	3.94E+01	2.30E+01	3.25E-02	9.73E+00	2.32E+01	3.25E-02	9.65E+00	2.66E+02	3.22E+04	2.16E+04
68.	4.70E+01	3.25E+01	3.87E-02	1.15E+01	3.22E+01	3.87E-02	1.15E+01	3.11E+02	2.31E+04	1.91E+04
70.	5.63E+01	4.95E+01	4.67E-02	1.40E+01	4.87E+01	4.68E-02	1.38E+01	3.60E+02	1.78E+04	1.09E+04
72.	6.47E+01	6.95E+01	5.28E-02	1.58E+01	6.80E+01	5.13E-02	1.53E+01	3.61E+02	1.25E+04	4.73E+03
74.	7.09E+01	9.43E+01	5.74E-02	1.71E+01	9.01E+01	5.43E-02	1.63E+01	3.73E+02	7.52E+03	1.54E+03
76.	7.22E+01	1.19E+02	5.72E-02	1.70E+01	1.09E+02	5.25E-02	1.55E+01	3.10E+02	3.57E+03	3.51E+02
78.	4.75E+01	8.45E+01	3.26E-02	9.32E+00	5.71E+01	2.20E-02	6.16E+00	5.86E+01	1.94E+02	3.23E+00
80.	6.41E+01	1.17E+02	3.36E-02	9.15E+00	4.94E+01	1.41E-02	3.69E+00	2.02E+01	2.17E+01	1.29E-01
82.	5.63E+01	9.49E+01	2.04E-02	5.22E+00	2.24E+01	4.81E-03	1.15E+00	4.03E+00	1.37E+00	3.57E-03
84.	4.08E+01	6.09E+01	9.71E-03	2.33E+00	8.20E+00	1.33E-03	2.91E-01	7.53E-01	1.62E-01	2.21E-04
86.	2.97E+01	3.81E+01	4.55E-03	1.04E+00	2.96E+00	3.54E-04	7.16E-02	1.43E-01	2.26E-02	1.70E-05
88.	1.91E+01	1.96E+01	1.65E-03	3.42E-01	7.42E-01	6.21E-05	1.12E-02	1.64E-02	2.13E-03	8.36E-07
90.	1.21E+01	9.30E+00	5.47E-04	1.01E-01	1.65E-01	9.45E-06	1.47E-03	1.57E-03	1.95E-04	3.86E-08

Table 5. Complete Printout of Calculations for 0605 UT, 3 November 1969 (Cont)

ALTITUDE	LA	LAMBDA	Q/E**2	PSUM	MSUM-E	[VT, SP	SP	INT. F	E	D
40.	4.51E+02	1.33E+05	1.07E+03	5.62E+04	5.63E+04	5.33E+04	5.63E+04	4.22E-01	4.22E-01	1.09E+02
42.	2.50E+02	6.74E+04	2.72E+02	6.18E+04	6.19E+04	6.19E+04	6.19E+04	9.19E-01	9.19E-01	2.30E+02
44.	1.44E+02	3.66E+04	8.05E+01	6.54E+04	6.56E+04	6.56E+04	6.56E+04	1.79E+00	1.79E+00	2.54E+02
46.	8.04E+01	1.96E+04	2.31E+01	6.81E+04	6.83E+04	6.83E+04	6.83E+04	3.44E+00	3.44E+00	2.80E+02
48.	4.50E+01	1.06E+04	6.75E+00	7.02E+04	7.07E+04	7.07E+04	7.07E+04	6.66E+00	6.66E+00	3.00E+02
50.	2.70E+01	6.20E+03	2.33E+00	7.25E+04	7.26E+04	7.26E+04	7.26E+04	1.17E+01	1.17E+01	3.20E+02
52.	1.57E+01	3.53E+03	8.04E-01	7.20E+04	7.20E+04	7.20E+04	7.20E+04	2.02E+01	1.94E+01	3.17E+02
54.	9.46E+00	1.86E+03	2.15E-01	8.49E+04	8.49E+04	8.49E+04	8.49E+04	4.73E+01	4.57E+01	4.44E+02
56.	5.42E+00	1.04E+03	6.98E-02	8.66E+04	8.66E+04	8.66E+04	8.66E+04	8.51E+01	8.28E+01	4.78E+02
58.	3.41E+00	6.73E+02	3.00E-02	8.44E+04	8.44E+04	8.44E+04	8.44E+04	1.34E+02	1.25E+02	4.69E+02
60.	2.01E+00	4.11E+02	1.13E-02	8.13E+04	8.13E+04	8.13E+04	8.13E+04	2.23E+02	2.19E+02	4.60E+02
62.	1.22E+00	2.56E+02	5.03E-03	7.88E+04	7.88E+04	7.88E+04	7.88E+04	3.41E+02	3.05E+02	4.66E+02
64.	7.04E-01	1.55E+02	2.07E-03	7.45E+04	7.45E+04	7.45E+04	7.45E+04	6.75E+02	6.75E+02	4.75E+02
66.	3.81E-01	9.45E+01	9.04E-04	6.83E+04	6.86E+04	6.86E+04	6.86E+04	1.21E+03	7.19E+02	4.69E+02
68.	2.23E-01	6.18E+01	4.64E-04	6.17E+04	6.15E+04	6.15E+04	6.15E+04	1.94E+03	9.79E+02	4.45E+02
70.	1.25E-01	3.82E+01	2.17E-04	5.49E+04	5.45E+04	5.45E+04	5.45E+04	3.30E+03	1.39E+03	4.20E+02
72.	7.05E-02	2.43E+01	1.07E-04	4.84E+04	4.80E+04	4.80E+04	4.80E+04	5.30E+03	1.89E+03	3.85E+02
74.	3.91E-02	1.56E+01	5.49E-05	4.26E+04	4.21E+04	4.21E+04	4.26E+04	6.24E+03	2.54E+03	3.55E+02
76.	2.15E-02	9.55E+00	2.75E-05	3.64E+04	3.63E+04	3.63E+04	3.73E+04	1.22E+04	3.44E+03	3.25E+02
78.	1.20E-02	1.70E+01	1.72E-05	1.54E+04	1.56E+04	1.56E+04	1.56E+04	1.54E+04	1.33E+04	3.05E+02
80.	6.05E-03	1.98E-04	7.22E-07	2.00E+04	2.01E+04	2.01E+04	2.01E+04	2.04E+04	2.00E+04	2.90E+02
82.	3.23E-03	2.10E-04	4.67E-07	2.51E+04	2.49E+04	2.49E+04	2.49E+04	2.32E+04	2.49E+04	2.90E+02
84.	1.70E-03	6.61E-05	4.48E-07	2.55E+04	2.54E+04	2.54E+04	2.54E+04	2.49E+04	2.54E+04	2.90E+02
86.	9.55E-04	2.53E-05	4.53E-07	2.53E+04	2.54E+04	2.54E+04	2.54E+04	2.54E+04	2.54E+04	2.90E+02
88.	4.94E-04	1.07E-05	4.53E-07	2.51E+04	2.53E+04	2.53E+04	2.53E+04	2.63E+04	2.53E+04	2.90E+02
90.	2.52E-04	4.59E-06	4.61E-07	2.51E+04	2.51E+04	2.51E+04	2.51E+04	2.66E+04	2.51E+04	2.90E+02

5. NUMERICAL EXAMPLE: August 1972 SPE

The final example presented (Table 6) is for one instance during the 3 to 11 August 1972 SPE. The temperature, T , and total molecular concentration, $[M]$ are for 1 August, 65°N , being interpolated from the CIRA 1972 models for 60°N and 70°N on 1 August. The ionization production rates are those for 1508 UT on 4 August.¹⁷ Computed $[e]$ agrees very well with data taken by the Chatanika backscatter radar at 62 km. However, above this altitude the model predicts electron concentrations 2 to 3 times greater than those reported.¹⁷ The situation is more serious below 62 km where model electron concentrations fall off more rapidly with decreasing altitude than do the data, the lowest altitude (50 km) measurement being $1 \times 10^4 \text{ cm}^{-3}$ whereas we compute $2.5 \times 10^3 \text{ cm}^{-3}$ (Table 6).

The disagreement is disappointing in view of the good results obtained with the model and the 2 to 5 November 1969 SPE. However, different seasonal factors may influence the important minor neutral species in such a way as to account for the differences. Note that we have used the same minor neutral concentrations O_3 , NO , NO_2 and $\text{O}_2(^1\Delta)$ as previously, but N_2 , O_2 , CO_2 and H_2O have changed since they are multiples of $[M]$ which has been altered. We have suggested¹⁸ that higher H_2O concentrations, say 10 ppmv, near the 80 km region would improve the model/data agreement considerably. The rationale for higher H_2O is that noctilucent clouds are prevalent in the high latitude summer mesosphere. The situation near 50 km is much more serious since the discrepancy is nearly an order of magnitude. A higher O_3 , and hence O concentration would help alleviate the problem, but in fact there is evidence¹⁹ that O_3 may have declined during this event due to the enhanced formation of NO resulting from proton ionization processes. A decrease in O_3 , and therefore O , not to mention an increase of NO , and hence NO_2^- , NO_3^- , would tend to make matters worse, if anything. The precision of the electron concentrations measured by the Chatanika radar below 60 km should be considered also. It may be that the $[e]$ values have an important systematic error with decreasing altitude below 60 km. We note that no data is given below 50 km indicating that this is the last acceptable data point. Deterioration of the $[e]$ -measurement may be setting in at a somewhat higher altitude. The Chatanika radar has been able to make D-region measurements only during this rather intense SPE.

17. Reagan, J. B., and Watt, T. M. (1976) Simultaneous satellite and radar studies of the D-region ionosphere during the intense solar particle events of August 1972, *J. Geophys. Res.* 81:4579-4596.

18. Swider, W., and Foley, C. I. (1977) The influence of minor atmospheric constituents on the electron loss rates of the August 4-11, 1972 and November 2-5 1969, solar proton events, *EOS*, 58:465.

19. Heath, D. F., Krueger, A. J., and Crutzen, P. J. (1971) Solar proton event: Influence on stratospheric ozone, *Science* 197:886-889.

Reagan and Watt¹⁷ claimed that ψ (or SI, see Eq. (1)) for this event agreed with the results⁴ for the 2 to 5 November 1969 SPE. However, the events were not normalized in terms of their appropriate T and [M] values. The ψ curves for the two events thus agree well, save for the 80-km region problem, only if T and [M] for the August 1972 SPE was similar to that for the 2 to 5 November 1969 event. This possibility appears to be remote. The 1 November 60° N CIRA 1972 T and [M] values used for the November SPE are corroborated by experimental²⁰ evidence.

20. Faire, A. C., and Murphy, E. A. (1972) in Proc. COSPAR Symp. on SPE of Nov. 1969, AFCRL-72-0474, pp 445-455.

Table 6. Complete Printout of Calculations for 1508 UT, 4 August 1972 (Cont)

ALTITUDE	02+	04+	02+.M20	M30+.J34	M30+	M30+.M2	M30+.J02	M502+	M50+.J02	M0+
40.	4.31E+01	1.95E+02	2.43E+02	1.73E+02	4.63E+01	1.31E+01	4.81E+02	7.40E+02	6.14E+02	3.79E+01
42.	9.91E+01	2.56E+02	3.15E+02	2.27E+02	8.16E+01	2.11E+01	6.29E+02	1.35E+03	8.31E+02	6.91E+01
44.	2.50E+02	3.22E+02	3.94E+02	2.84E+02	1.41E+02	2.64E+01	7.87E+02	2.29E+03	1.10E+03	1.18E+02
46.	4.63E+02	4.03E+02	4.97E+02	3.55E+02	2.32E+02	3.40E+01	9.40E+02	3.75E+03	1.40E+03	1.96E+02
48.	8.60E+02	4.95E+02	6.09E+02	4.34E+02	3.67E+02	4.04E+01	1.20E+03	5.91E+03	1.73E+03	3.13E+02
50.	1.51E+03	6.25E+02	7.65E+02	5.46E+02	6.04E+02	5.08E+01	1.50E+03	2.17E+03	2.54E+03	5.28E+02
52.	2.16E+03	7.54E+02	9.15E+02	6.54E+02	9.12E+02	6.33E+01	1.79E+03	1.44E+04	2.54E+03	7.95E+02
54.	2.97E+03	9.06E+02	1.10E+03	7.81E+02	1.38E+03	7.72E+01	2.12E+03	2.15E+04	2.91E+03	1.21E+03
56.	3.90E+03	1.04E+03	1.25E+03	8.91E+02	1.80E+03	8.10E+01	2.44E+03	2.86E+04	3.97E+03	1.66E+03
58.	5.02E+03	1.21E+03	1.47E+03	1.02E+03	2.37E+03	9.17E+01	2.70E+03	3.72E+04	5.00E+03	2.29E+03
60.	6.37E+03	1.37E+03	1.60E+03	1.13E+03	3.57E+03	1.16E+02	2.95E+03	4.57E+04	6.88E+03	3.01E+03
62.	7.92E+03	1.47E+03	1.68E+03	1.19E+03	4.43E+03	1.12E+02	3.01E+03	4.94E+04	8.39E+03	3.69E+03
64.	9.63E+03	1.55E+03	1.85E+03	1.31E+03	5.06E+03	1.31E+02	3.13E+03	5.16E+04	1.07E+04	4.67E+03
66.	1.14E+04	1.62E+03	1.98E+03	1.39E+03	7.55E+03	1.51E+02	3.13E+03	4.90E+04	1.19E+04	5.71E+03
68.	1.37E+04	2.03E+03	2.12E+03	1.43E+03	9.46E+03	1.40E+02	3.11E+03	4.53E+04	7.87E+02	6.64E+03
70.	1.63E+04	2.34E+03	2.33E+03	1.61E+03	1.23E+02	1.54E+02	3.13E+03	4.11E+04	4.87E+02	7.89E+03
72.	1.96E+04	2.75E+03	2.57E+03	1.76E+03	1.61E+02	1.59E+02	3.10E+03	3.62E+04	2.84E+02	8.84E+03
74.	2.23E+04	3.39E+03	2.91E+03	1.95E+03	2.21E+02	1.30E+02	3.07E+03	3.16E+04	1.56E+02	1.00E+04
76.	2.59E+04	4.02E+03	3.16E+03	2.10E+03	2.79E+02	2.14E+02	2.93E+03	2.72E+04	8.91E+01	1.05E+04
78.	3.05E+04	4.64E+03	3.36E+03	2.17E+03	3.33E+02	2.44E+02	2.57E+03	2.09E+04	4.12E+01	1.15E+04
80.	3.61E+04	4.62E+03	2.67E+03	1.61E+03	3.35E+02	1.52E+02	1.34E+03	9.19E+03	5.58E+00	1.45E+04
82.	4.17E+04	1.41E+03	4.37E+02	4.37E+02	1.21E+02	4.16E+01	2.36E+02	1.35E+03	5.16E+01	1.70E+04
84.	4.52E+04	5.78E+02	1.97E+02	9.33E+01	3.43E+01	8.37E+01	3.33E+01	1.86E+02	3.13E+02	1.83E+04
86.	4.75E+04	1.73E+02	4.35E+01	1.80E+01	8.25E+01	1.68E+02	3.94E+00	2.49E+01	2.06E+03	1.98E+04
88.	5.13E+04	5.05E+01	8.63E+00	2.89E+00	1.53E+00	1.59E+03	1.00E+01	2.57E+00	5.77E+05	2.14E+04
90.	5.37E+04	1.53E+01	1.74E+00	4.50E+01	2.48E+01	1.57E+04	1.99E+02	2.66E+01	3.84E+06	2.31E+04

ALTITUDE	N0+.J02	N0+.M20	N0+.M20.N2	N0+.M20.C02	N0+.M20	N3+.M20.M2	N0+.M20.J02	N0+.M20	N703+	M90+
40.	6.51E+01	1.55E+00	5.39E+02	1.62E+01	1.55E+00	5.17E+02	1.61E+01	4.62E+02	4.17E+05	2.63E+05
42.	8.54E+01	2.93E+00	7.10E+02	2.13E+01	2.92E+00	7.07E+02	2.12E+01	6.07E+02	5.26E+05	1.62E+05
44.	1.03E+02	5.33E+00	9.00E+02	2.70E+01	5.31E+00	8.37E+02	2.69E+01	7.60E+02	6.11E+05	6.43E+04
46.	1.37E+02	9.07E+00	1.44E+03	3.41E+01	9.04E+00	1.13E+03	3.39E+01	9.65E+02	6.15E+05	3.58E+04
48.	1.70E+02	1.46E+01	1.41E+03	4.22E+01	1.47E+01	1.40E+03	4.20E+01	1.19E+03	5.95E+05	2.18E+04
50.	2.17E+02	2.51E+01	1.80E+03	5.38E+01	2.50E+01	1.79E+03	5.36E+01	1.51E+03	5.47E+05	1.37E+04
52.	2.61E+02	3.74E+01	2.16E+03	6.47E+01	3.72E+01	2.15E+03	6.43E+01	1.79E+03	4.74E+05	1.05E+04
54.	3.13E+02	5.61E+01	2.59E+03	7.75E+01	5.57E+01	2.57E+03	7.71E+01	2.11E+03	3.66E+05	7.85E+03
56.	3.54E+02	7.37E+01	2.93E+03	8.77E+01	7.32E+01	2.91E+03	8.69E+01	2.31E+03	2.71E+05	7.39E+03
58.	4.05E+02	9.72E+01	3.28E+03	9.82E+01	9.82E+01	3.25E+03	9.70E+01	2.45E+03	1.74E+05	6.57E+03
60.	4.55E+02	1.20E+02	3.59E+03	1.07E+02	1.19E+02	3.59E+03	1.07E+02	2.69E+03	1.08E+05	6.75E+03
62.	4.95E+02	1.36E+02	3.67E+03	1.09E+02	1.33E+02	3.72E+03	1.07E+02	2.85E+03	3.31E+04	7.15E+03
64.	4.63E+02	1.58E+02	3.85E+03	1.14E+02	1.53E+02	3.72E+03	1.10E+02	2.05E+03	3.22E+04	6.05E+03
66.	4.71E+02	1.76E+02	3.84E+03	1.13E+02	1.67E+02	3.50E+03	1.06E+02	1.70E+03	1.64E+04	3.46E+03
68.	4.63E+02	1.84E+02	3.75E+03	1.10E+02	1.71E+02	3.50E+03	1.01E+02	1.38E+03	1.02E+04	1.74E+03
70.	4.50E+02	1.89E+02	3.61E+03	1.05E+02	1.71E+02	3.28E+03	9.34E+01	1.07E+03	6.19E+03	7.21E+02
72.	4.13E+02	1.82E+02	3.32E+03	9.51E+01	1.60E+02	2.91E+03	8.15E+01	7.79E+02	3.67E+03	2.85E+02
74.	3.76E+02	1.74E+02	2.92E+03	8.24E+01	1.45E+02	2.43E+03	6.66E+01	5.14E+02	2.04E+03	1.01E+02
76.	3.29E+02	1.54E+02	2.50E+03	6.94E+01	1.22E+02	1.96E+03	5.29E+01	3.44E+02	1.23E+03	4.29E+01
78.	2.80E+02	1.35E+02	2.06E+03	5.57E+01	9.74E+01	1.49E+03	3.83E+01	1.93E+02	5.99E+02	1.33E+01
80.	2.53E+02	1.19E+02	1.71E+03	4.32E+01	6.95E+01	1.00E+03	2.34E+01	7.40E+01	1.34E+02	1.50E+00
82.	1.82E+02	8.34E+01	1.02E+03	2.27E+01	3.16E+01	3.30E+02	7.69E+00	1.40E+01	8.09E+00	4.32E+02
84.	1.15E+02	5.20E+01	4.90E+02	9.60E+00	1.49E+01	1.30E+02	1.87E+00	2.30E+00	6.44E+01	1.52E+03
86.	6.92E+01	2.95E+01	1.96E+02	3.33E+00	3.46E+00	2.11E+03	2.23E+01	2.79E+01	4.31E+02	8.95E+05
88.	3.47E+01	1.21E+01	4.88E+01	6.89E+01	1.53E+01	2.15E+03	2.25E+02	1.26E+02	1.66E+03	7.39E+07
90.	1.67E+01	4.26E+00	1.00E+03	1.07E+01	5.77E+02	1.35E+05	1.09E+03	4.12E+03	6.10E+05	1.08E+08

Table 6. Complete Printout of Calculations for 1508 UT, 4 August 1972 (Cont)

ALTITUDE	LA	LAMBDA	Q/E**2	PSUN	MSUN+E	INT. SP	SP	INT. E	E	Q
40.	7.48E+02	8.25E+03	4.11E+00	7.04E+05	7.05E+05	7.04E+05	7.06E+05	5.40E+01	8.54E+01	3.00E+04
42.	4.22E+02	3.68E+03	8.29E-01	6.92E+05	6.92E+05	6.91E+05	6.92E+05	1.56E+02	1.88E+02	2.93E+04
44.	2.65E+02	1.96E+03	2.39E-01	6.81E+05	6.81E+05	6.79E+05	6.81E+05	4.38E+02	3.48E+02	2.88E+04
46.	1.62E+02	1.01E+03	6.47E-02	6.69E+05	6.63E+05	6.30E+05	6.63E+05	1.19E+03	6.58E+02	2.80E+04
48.	1.01E+02	5.17E+02	1.80E-02	6.30E+05	6.30E+05	6.11E+05	6.32E+05	3.29E+03	1.22E+03	2.70E+04
50.	5.9E+01	2.31E+02	4.10E-03	5.80E+05	5.83E+05	5.55E+05	5.82E+05	7.14E+03	2.52E+03	2.60E+04
52.	3.74E+01	1.10E+02	1.17E-03	5.11E+05	5.12E+05	4.45E+05	5.11E+05	1.21E+04	4.61E+03	2.48E+04
54.	2.24E+01	4.90E+01	1.35E-04	4.11E+05	4.13E+05	3.15E+05	4.12E+05	1.81E+04	8.27E+03	2.30E+04
56.	1.42E+01	2.50E+01	1.38E-04	3.24E+05	3.24E+05	2.38E+05	3.24E+05	3.22E+04	1.25E+04	2.12E+04
58.	8.95E+00	1.16E+01	5.38E-05	2.37E+05	2.36E+05	1.81E+05	2.36E+05	3.45E+04	1.89E+04	1.90E+04
60.	5.31E+00	6.02E+00	2.58E-05	1.80E+05	1.81E+05	1.41E+05	1.81E+05	4.40E+04	2.57E+04	1.70E+04
62.	3.35E+00	3.35E+00	1.41E-05	1.39E+05	1.40E+05	1.10E+05	1.40E+05	4.76E+04	3.20E+04	1.45E+04
64.	1.95E+00	1.72E+00	7.66E-06	1.10E+05	1.10E+05	1.30E+05	1.10E+05	5.27E+04	4.04E+04	1.25E+04
66.	1.13E+00	8.96E-01	4.67E-06	8.93E+04	9.00E+04	1.59E+05	8.98E+04	5.64E+04	4.74E+04	1.05E+04
68.	6.71E-01	5.19E-01	3.41E-06	7.75E+04	7.80E+04	1.54E+05	7.80E+04	6.12E+04	5.14E+04	9.00E+03
70.	3.75E-01	2.89E-01	2.66E-06	6.94E+04	6.98E+04	1.42E+05	6.98E+04	6.58E+04	5.42E+04	7.60E+03
72.	2.00E-01	1.51E-01	2.21E-06	6.30E+04	6.34E+04	1.31E+05	6.34E+04	6.80E+04	5.51E+04	6.70E+03
74.	1.03E-01	7.16E-02	1.92E-06	5.91E+04	5.95E+04	1.22E+05	5.95E+04	7.01E+04	5.44E+04	5.90E+03
76.	5.62E-02	3.35E-02	1.75E-06	5.62E+04	5.63E+04	1.15E+05	5.63E+04	7.59E+04	5.44E+04	5.20E+03
78.	2.82E-02	1.99E-02	1.52E-06	5.56E+04	5.57E+04	1.07E+05	5.57E+04	8.44E+04	5.51E+04	4.60E+03
80.	1.28E-02	1.09E-03	9.47E-07	6.65E+04	6.67E+04	1.03E+05	6.67E+04	9.35E+04	6.66E+04	4.20E+03
82.	5.51E-03	3.24E-04	5.53E-07	8.35E+04	8.40E+04	9.16E+04	8.40E+04	9.52E+04	8.45E+04	3.90E+03
84.	2.32E-03	8.51E-05	4.99E-07	8.43E+04	8.49E+04	9.14E+04	8.49E+04	9.73E+04	8.49E+04	3.60E+03
86.	1.01E-03	2.57E-05	4.99E-07	9.11E+04	9.20E+04	9.15E+04	8.20E+04	9.93E+04	8.20E+04	3.35E+03
88.	3.98E-04	8.31E-06	5.01E-07	7.88E+04	7.93E+04	8.18E+04	7.93E+04	9.92E+04	7.93E+04	3.15E+03
90.	1.67E-04	2.97E-06	5.00E-07	7.68E+04	7.74E+04	8.56E+04	7.74E+04	1.00E+05	7.74E+04	3.00E+03

References

1. Swider, W., and Foley, C.I. (1975) Computer Program for the Disturbed Steady-State Nighttime D-Region, AFCRL-TR-75-0150.
2. Swider, W., and Narcisi, R.S. (1975) A study of the nighttime D-region during a PCA event, J. Geophys. Res. 80:655-664.
3. Swider, W., Keneshea, T.J., and Foley, C.I. (1978) An SPE-disturbed D-region model, Planet. Space Sci. 26: 26.
4. Swider, W., and Dean, W.A. (1975) Effective electron loss coefficient of the disturbed daytime D-region, J. Geophys. Res. 80:1815-1819.
5. Swider, W., Narcisi, R.S., Keneshea, T.J., and Ulwick, J.C. (1971) Electron loss during a nighttime PCA event, J. Geophys. Res. 76:4691-4694.
6. Smith, D., Adams, N.G., and Church, M.J. (1976) Mutual neutralization rates of ionospherically important ions, Planet. Space Sci. 24:697-703.
7. Vanderhoff, J.A., and Niles, F.E. (1976) Recent development in measurements of photodissociation for atmospheric positive ions, EOS, 57:303.
8. Johnsen, R., Huang, C.-M., and Biondi, M.A. (1975) The formation and breakup of $\text{NO}^+ \cdot \text{N}_2$ clusters in N_2 at low temperatures, J. Chem. Phys. 63:3374-3378.
9. Heimerl, J.M. (1976) Values for Selected Collisional Dissociation Rate Coefficients of Positive Clustered Ions, BRL-IMR-499.
10. Ferguson, E.E. (1975) in Atmospheres of Earth and the Planets (Ed. B.M. McCormac) Reidel, Dordrecht, Holland, pp 197-210.
11. Ferguson, E.E. (1977) Paper presented at IAGA meeting in Seattle, Washington.
12. Peterson, J.R., Cosby, P.C., and Moseley, J.T. (1977) Photo-destruction of atmospheric negative and positive ions, Space Res. 17:243-246.
13. Niles, F.E. (1976) private communication.
14. Dean, W.A. (1972) in Proc. COSPAR Symp. on SPE of Nov. 1969, AFCRL-72-0474, pp 291-306.

References

15. Narcisi, R.S., Philbrick, C.R., Thomas, D.M., Bailey, A.D., Wlodyka, L.E., Baker, D., Federico, G., Wlodyka, R., and Gardner, M.E. (1972) in Proc. COSPAR Symp. on SPE of Nov. 1969, AFCRL-72-0474, pp 421-432.
16. Moseley, J.T., Cosby, P.C., and Peterson, J.R. (1977) Laboratory measurements of photodissociation and photodetachment cross-sections of atmospheric ions, EOS 58:698.
17. Reagan, J.B., and Watt, T.M. (1976) Simultaneous satellite and radar studies of the D-region ionosphere during the intense solar particle events of August 1972, J. Geophys. Res. 81:4579-4596.
18. Swider, W., and Foley, C.I. (1977) The influence of minor atmospheric constituents on the electron loss rates of the August 4-11, 1972 and November 2-5, 1969, solar proton events, EOS, 58:465.
19. Heath, D.F., Krueger, A.J., and Crutzen, P.J. (1971) Solar proton event: Influence on stratospheric Ozone, Science 197:886-889.
20. Faire, A.C., and Murphy, E.A. (1972) in Proc. COSPAR Symp. on SPE of Nov. 1969, AFCRL-72-0474, pp 445-455.

Appendix A

Steady-State Multi-Ion Disturbed D-Region Model Program
(Subroutine Initial, which contains input profiles of
Q, M, T, minor neutrals and Si, has been omitted.)


```

5 C      40 - 90 KM IN INCREMENTS OF 2
C
C      78 REACTIONS
C
PROGRAM DREGION(INPUT=65,OUTPUT=65,TAPE15=65,TAPE2)
10 COMMON NEUT(9,26),TEMP(26),M(26),Z(26),Q(26),SI(26)
   DIMENSION NION(8,26),NSPECI(8),PION(30,26),C(100),ESAVE(26)
   1      , ISPECI(30), INEUT(9), A(100), B(100),D(100),IREAC(100),
   2      JDUM(26), ITER(26), REAC(6)
   DIMENSION ICJEFF(26),EINT(26),SPINT(26),ICOL(2),EVENT(2)
15 REAL M,K,NEUT,NION
   INTEGER WATER,TPF,PCA
   REAL ICJEFF
   LOGICAL IONCF,DAY,FIRST,DIAGNOS
   DATA ICOL/104 INT. E ,104 INT. SP /
20 C
C      NALT=NUMBER OF ALTITUDES, ISTART IS INDEX OF STARTING ALTITUDE,
C      NELE=NUMBER OF ELEMENTS IN PION ARRAY TO BE COMPUTED
C
C      NELE=30
25 FIRST=.TRUE.
C
C      READ IN COMPUTER RUN OPTIONS
C
C      READ 72, ISTART,NALT
30 72 FORMAT(2I5)
   IF(EOF(5LINPUT)) 99,73
   73 READ 69,SET,ISET
   69 FORMAT(A10,I5)
   PRINT 69, SET
35 74 READ 70,DAY,WATER,TPF,PCA,IONCF,DIAGNOS,CRIT,OD,EVENT(1),EVENT(2)
   70 FORMAT(1L2,3A2,2L2,2F5.0,2A10)
   IF(EOF(5LINPUT)) 99,71
   71 PRINT 67,DAY,WATER,TPF,PCA,IONCF,OD,CRIT,EVENT(1),EVENT(2)
   67 FORMAT(* DAY=*,L2,* H2O=*,A2,* TPF=*,A2,* PCA=*,A2,* IONCF=*,L2,
40 1      * OD=*,F5.0* CRITERIA=*,F5.0* PERCENT*,
   2      /* *,2A10)
C
C      DETERMINE SPECIE PROFILES AND OTHER PARAMETERS WHICH DESCRIBE THIS
C      COMPUTER RUN - FOUND IN SUBROUTINE INITIAL
45 C
C      CALL INITIAL(DAY,WATER,TPF,PCA)
C
C      PRINT 75 ,Z(ISTART),Z(NALT)
50 75 FORMAT(5X,*ALTITUDE RANGE *, F5.0,* -*,F5.0),* KM*)
   DD=0.
   IF(DAY) DD=1.
   IYES=0      $      NOS=NALT-ISTART+1
C
C      OD= OPTICAL DEPTH FACTOR
55 C
C      COMPUTE THE IONIZATION COEFFICIENTS FOR EACH ALTITUDE
C
C      SIGMA=1.0E-20
C      IF(IONCF) 7,9

```

```

60      7 DO 6 J=ISTART,NALT
        H=(3032.*TEMP(J))/(6370./(6370.+Z(J)))*2)
        ICOEFF(J)=4.7E-07*EXP(-(NEUT(2,J)*H*SIGMA*0))
        PION(30,J)=ICOEFF(J)*NEUT(5,J)
        8 CONTINUE
65      GO TO 15
      2 (NO)*I WILL NOT BE COMPUTED THIS RUN
        9 NELE=29
        15 CONTINUE
        TODAY=10H
70      RUNDY=DATE(TODAY)
        WRITE(2,150) RUNDY,SET
        150 FORMAT(1H1,15X,*RUN DATE*,A10,15X,*REACTION SET OF*,A10)
        ALPHAD=4.0E-07
        ALPHAI=6.0E-08
75      TIME=10HDAY
        IF( .NOT. DAY) TIME=10HNTG4T
        WRITE(2,151) ALPHAD,ALPHAI,TIME,WATER,TPF,PCA,CRIT,
          1 EVENT(1),EVENT(2)
        151 FORMAT(5X,*AD=*,1PE9.1,* AI=*,1PE8.1,2X,A10,*, H2O=*,A2,
80      1 *,TEMP=*,A2,*, PCA=*,A2,* CRITERIA=*,0PF5.0,* PERCENT*,
          2 *, EVENT *,2A10)
        CRIT=CRIT/100.
        IF(IONCF) 11,13
        11 WRITE(2,12) 30,SIGMA
85      12 FORMAT(10X,*OPTICAL DEPTH FACTOR = *,F5.2,* SIGMA = *,1PE9.1)
        13 NREAC=78
        IF( .NOT. FIRST) GO TO 19
        IF( PCA .EQ. 2HLO .OR. PCA .EQ. 2HMI ) GO TO 18
        IF(PCA .EQ. 2H72) 36,37
90      36 READ 16, (Q(I),I=1,25)
        17 FORMAT(12F6.0)
        16 FORMAT(1P7E10.2)
        IF(EOF(5LINPUT)) 99,18
        37 READ 17, (Q(I),I=1,25)
95      IF(EOF(5LINPUT))99,18
        18 CONTINUE
      2
      C
      C
100     DO 20 II=1,NREAC
        READ(15,1) I,(REAC(L),L=1,6),A(I),B(I),D(I)
        1 FORMAT(I4,A10,2A5,1X,A10,2A6,1PE9.2,0PF5.1,1PE9.2)
        IREAC(II)=I
        IF(EOF(15)) 22,21
105     21 IF(TSET .EQ. 0) GO TO 20
        WRITE(2,2) IREAC(I),(REAC(L),L=1,6),A(I),B(I),D(I)
        2 FORMAT(I4,A10,2A6,14=,A10,2A6,1PE9.2,0PF5.1,1PE9.2)
        20 CONTINUE
        GO TO 19
110     22 NREAC=I-1
        19 CONTINUE
        WRITE(2,805) NREAC
        805 FORMAT(* THE NUMBER OF REACTIONS THIS RUN *,I10)
      2

```

```

115 C      ISPECI IS A HOLLERITH ARRAY CONTAINING CHEMICAL SYMBOLS OF PION
      C      ARRAY ( POSITIVE ION ARRAY)
      C
      C
120 C      NSPECI IS HOLLERITH ARRAY CONTAINING CHEMICAL SYMBOLS OF
      C      NEON ARRAY (NEGATIVE ION ARRAY)
      C
      C      ISPECI(1)=10HE          $      NSPECI(1)=10H02-
      C      ISPECI(2)=10HSP        $      NSPECI(2)=10H04-
      C      ISPECI(3)=10MNSUM      $      NSPECI(3)=10HC04-
125 C      ISPECI(4)=10H02+        $      NSPECI(4)=10H03-
      C      ISPECI(5)=10H04+        $      NSPECI(5)=10HC03-
      C      ISPECI(6)=10H02+.H2O   $      NSPECI(6)=10H0-
      C      ISPECI(7)=10HH30+.OH    $      NSPECI(7)=10HNO2-
      C      ISPECI(8)=10HH30+      $      NSPECI(8)=10HNO3-
130 C      ISPECI(9)=10HH30+.N2
      C      ISPECI(10)=10HH30+.CO2
      C      ISPECI(11)=10HH5O2+
      C      ISPECI(12)=10HH5O+.CO2
      C      ISPECI(13)=10HNO+
135 C      ISPECI(14)=10HNO+.N2
      C      ISPECI(15)=10HNO+.CO2
      C      ISPECI(16)=10HNO+.H2O
      C      ISPECI(17)=10HNO+.H2O.N2
      C      ISPECI(18)=10HNO+H2O.CO2
140 C      ISPECI(19)=10HNO+.2H2O
      C      ISPECI(20)=10HNO+.242ON2
      C      ISPECI(21)=10HNO+2H2OCO2
      C      ISPECI(22)=10HNO+.3H2O
      C      ISPECI(23)=10HH7O3+
145 C      ISPECI(24)=10HH9O4+
      C      ISPECI(25)=10H LA
      C      ISPECI(26)=10HLA430A
      C      ISPECI(27)=10HQ/E**2
      C      ISPECI(28)=10HPSUM
150 C      ISPECI(29)=10MNSUM+E
      C      ISPECI(30)=10H(NO).I
      C
      C      INEUT IS A HOLLERITH ARRAY CONTAINING CHEMICAL SYMBOLS OF NEUTRAL
      C      SPECIES
155 C
      C      INEUT(1)=10H0
      C      INEUT(2)=10H02
      C      INEUT(3)=10H03
      C      INEUT(4)=10H02
160 C      INEUT(5)=10HNO
      C      INEUT(6)=10HC02
      C      INEUT(7)=10H2O
      C      INEUT(8)=10H02(1)
      C      INEUT(9)=10HNO2
165 C
      C      IF(.NOT. DIAGNOS) GO TO 49
      C      WRITE(2,271) (ISPECI(J),J=25,29),ICOL(2),ISPECI(2),
      C      ICOL(1),ISPECI(1)
      C      49 CONTINUE
170 C
      C      ITER ARRAY OF NUMBER OF ITERATIONS TO COMPUTE E
      C      JOUN;ARRAY OF SWITCHES INDICATING CRITERIA SATISFIED

```



```

175      DO 25 J=ISTART,NALT
          ITER(J)=0
          JOUN(J)=3H N3
25      DO LOOP 100 CALCULATES ALL THE POSITIVE IONS
180      DO 100 J=ISTART,NALT
          IF(JOUN(J) .EQ. 3HYES) GO TO 100
          ITER(J)=ITER(J)+1
185      CALL RATECN(K,A,B,D,IREAC,TEMP,J,NREAC)
          IF(ITER(J) .GT. 1) GO TO 30
          PION(25,J)=NEUT(2,J)*(K(61)*NEUT(2,J)+K(62)*NEUT(4,J))
          IF(DAY) 51,52
190      51 PION(1,J)=SQRT(Q(J)/SI(J))
          GO TO 53
          52 PION(1,J)=SQRT((PION(25,J)/(2.*ALPHA))**2+1(J)/ALPHA)
          1 -PION(25,J)/(2.*ALPHA)
          53 PION(2,J)=SQRT((Q(J)*(5.*NEUT(1,J)/ALPHA+NEUT(3,J)/ALPHA))/
          1 (5.*NEUT(1,J)+NEUT(3,J)))
195      EINT(J)=PION(1,J)
          SPINT(J)=PION(2,J)
          90 AISP=ALPHA*I*PION(2,J)
          CALL REGION(DAY,NION,K,PION(25,J),PION(1,J),J,AISP,PION(3,J))
          AISP=ALPHA*I*PION(3,J)
200      CON1=K(8)*NEUT(1,J)+K(9)*NEUT(7,J)+K(42)*M(J)+DD*K(4)+AISP
          CON2=K(7)*NEUT(2,J)*M(J)
          CON4=NEUT(7,J)*(K(10)+K(11))+AISP+K(30)*PION(1,J)+DD*K(5)
          CON5=DD*K(4)+(DD*K(5)*K(9)*NEUT(7,J)/CON4)
          PION(4,J)=.9*Q(J)/(AISP+K(27)*PION(1,J)+CON2+K(6)*
205      1 NEUT(5,J)-(CON2*(K(8)*NEUT(1,J)+K(42)*M(J)+CON5)/
          1 (CON1+K(28)*PION(1,J)))
          PION(5,J)=PION(4,J)*(CON2/(CON1+K(28)*PION(1,J)))
          PION(6,J)=PION(5,J)*K(9)*NEUT(7,J)/CON4
          PION(7,J)=K(10)*NEUT(7,J)*PION(6,J)/
210      1 (K(12)*NEUT(7,J)+AISP+K(30)*PION(1,J))
          PION(8,J)=PION(6,J)*K(11)*NEUT(7,J)/
          1 (K(31)*PION(1,J)+K(18)*NEUT(7,J)*M(J)+
          2 K(13)*NEUT(4,J)**2+AISP)
          CON1=K(14)*NEUT(5,J)
          CON2=K(32)*PION(1,J)+AISP
215      PION( 9,J)=(K(13)*NEUT(4,J)*NEUT(4,J)*PION(1,J))/
          1 (CON1+K(35)*PION(1,J)+AISP)
          CON3=K(15)*NEUT(7,J)
          PION(10,J)=(CON1*PION( 9,J))/(CON3+K(36)*PION(1,J)+AISP)
220      H2OM1=NEUT(7,J)*M(J)
          PION(11,J)=(PION(7,J)*K(12)*NEUT(7,J)+K(18)*PION(8,J)*H2OM1+
          1 PION(10,J)*CON3)/
          1 (K(32)*PION(1,J)+K(19)*H2OM1+AISP+
          1 K(16)*NEUT(6,J)*M(J))
225      PION(12,J)=(K(16)*NEUT(6,J)*PION(11,J)*M(J)/
          1 (K(37)*PION(1,J)+AISP+K(17)*NEUT(7,J))
          CON1=K(21)*NEUT(5,J)*NEUT(4,J)
          CON2=K(22)*NEUT(7,J)
          SQN2=NEUT(4,J)*NEUT(4,J)

```

```

230 PION(13,J)=(.1*Q(J)+K(6)*NEUT(5,J)*PION(4,J)+PION(30,J))/
1 (K(26)*PION(1,J)+CON1+AISN
2 +K(43)*SQN2-(K(43)*SQN2*NEUT(4,J)*K(51)/
3 (K(44)*NEUT(6,J)+K(38)*PION(1,J)+AISN+K(51)*NEUT(4,J)))
PION(14,J)=(K(43)*PION(13,J)*SQN2)/
235 1 (K(44)*NEUT(6,J)+K(38)*PION(1,J)+AISN+K(51)*NEUT(4,J))
PION(15,J)=(CON1*PION(13,J)+K(44)*NEUT(6,J)*PION(14,J))/
1 (CON2+K(38)*PION(1,J)+AISN)
CON1=K(23)*NEUT(7,J)*NEUT(4,J)
PION(16,J)=CON2*PION(15,J)/(CON1+K(39)*PION(1,J)+AISN
240 1 +K(45)*SQN2)
PION(17,J)=(PION(16,J)*K(45)*SQN2)/
1 (K(46)*NEUT(6,J)+K(40)*PION(1,J)+AISN)
PION(18,J)=(PION(17,J)*K(46)*NEUT(6,J))/
1 (K(47)*NEUT(7,J)+K(40)*PION(1,J)+AISN)
245 CON2=K(24)*NEUT(7,J)*NEUT(4,J)
PION(19,J)=(CON1*PION(16,J)+PION(18,J)*K(47)*NEUT(7,J))/
1 (K(40)*PION(1,J)+CON2+AISN+K(48)*SQN2)
PION(20,J)=(PION(19,J)*K(48)*SQN2)/
1 (K(49)*NEUT(6,J)+K(41)*PION(1,J)+AISN)
250 PION(21,J)=(PION(20,J)*K(49)*NEUT(6,J))/
1 (K(50)*NEUT(7,J)+K(41)*PION(1,J)+AISN)
PION(22,J)=(CON2*PION(19,J)+PION(21,J)*K(50)*NEUT(7,J))/
1 (K(25)*NEUT(7,J)+K(41)*PION(1,J)+AISN)
G=K(34)*PION(1,J)+AISN+K(52)*M(J)
255 PION(23,J)=(PION(11,J)*K(19)*H2OM1+PION(22,J)*K(25)*NEUT(7,J)+
1 K(17)*PION(12,J)*NEUT(7,J))/
1 (K(33)*PION(1,J)+K(20)*H2OM1*(1-K(52)*M(J)/G)+AISN)
PION(24,J)=(PION(23,J)*K(20)*H2OM1)/G
PION(26,J)=PION(3,J)/PION(1,J)
260 PION(27,J)=Q(J)/PION(1,J)**2
PION(29,J)=PION(3,J)+PION(1,J)
100 CONTINUE
3 IF(JUMP.EQ.2) GO TO 126
265 C COMPUTE THE SUM OF THE POSITIVE IONS
DO 120 J=ISTART,NALT
IF(ITER(J).GE.20) JDUN(J)=3HNO
IF(JDUN(J).EQ.3HYES) GO TO 120
270 ESAVE(J)=PION(1,J)
PION(28,J)=0.
DO 121 I=4,24
121 PION(28,J)=PION(28,J)+PION(I,J)
IF(ABS(1.-PION(29,J)/PION(28,J)).LE.CRIT) JDUN(J)=3HYES
275 IF(JDUN(J).EQ.3HYES) GO TO 119
PION(2,J)=.5*(ESAVE(J)+PION(28,J)+PION(3,J))
118 PION(1,J)=.5*(ESAVE(J)+PION(28,J)/(1.+PION(26,J)))
GO TO 120
119 IYES=IYES+1
280 NOS=NOS-1
120 CONTINUE
IF(DIAGNOS)40,49
40 J=ISTART
WRITE(2,269) Z(J),(PION(I,J),I=25,29),SPINT(J),PION(2,J),EINT(J),

```

```

285      1      PION(1,J),ITER(J),JDUN(J)
          IF(ITER(J) .GE. 20) 125,50
      49 CONTINUE
      ;      IF(ITER(ISTART) .EQ. 1) GO TO 122
          DO 125 J=ISTART,NALT
290      IF(JDUN(J) .EQ. 3H NO) GO TO 50
      125 CONTINUE
          PRINT*, " THE SCORE IS ",IVES," YES AND ",VJS, "NO"
      122 WRITE(2,200) (INEUT(I),I=1,9)
      200 FORMAT(/" ALTITUDE",3X,9(A10),2X,"M",9X,"TEMP")
295      DO 235 J=ISTART,NALT
          WRITE(2,240) Z(J), (VEUT(I,J),I=1,9),H(J),TEMP(J)
      240 FORMAT(0PF10.0,11(1X,1PE9.2))
      235 CONTINUE
          WRITE(2,273) ISPECI(1),ISPECI(3), (NSPECI(J),J=1,8)
300      273 FORMAT(/" ALTITUDE ",2X,11(1X,A10))
          DO 272 J=ISTART,NALT
          WRITE(2,274) Z(J), PION(1,J),PION(3,J), (NION(I,J),I=1,8)
      274 FORMAT(F10.0,11(2X,1PE9.2))
      272 CONTINUE
305      IL=3
          DO 270 I=1,2
          IM=IL+1
          IL=IM+10
          IF(IL .GT. 24) IL=24
310      WRITE(2,273) (ISPECI(J),J=IM,IL)
          DO 276 J=ISTART,NALT
          WRITE(2,274) Z(J), (PION(N,J),N=IM,IL)
      276 CONTINUE
      270 CONTINUE
315      WRITE(2,271) (ISPECI(J),J=25,29),ICOL(2),ISPECI(2),
          1      ICOL(1),ISPECI(1)
      271 FORMAT(/" ALTITUDE ",2X,9(1X,A10),2X,"Q",7X," ITER")
          DO 275 J=ISTART,NALT
          WRITE(2,269) Z(J), (PION(I,J),I=25,29),SPINT(J),PION(2,J),EINT(J),
320      1      PION(1,J),Q(J),ITER(J)
      269 FORMAT(0PF10.0,10(2X,1PE9.2),2X,I5)
      275 CONTINUE
      ;      IF(ITER(ISTART) .EQ. 1) GO TO 50
          FIRST=.FALSE.
325      GO TO 74
      99 CONTINUE
          CALL EXIT
          END

```


SUBROUTINE NEGION

```

1      SUBROUTINE NEGION(DAY,NION,K,LA,E,J,AISP,SUM)
      C
      C      SUBROUTINE NEGION COMPUTES THE CONCENTRATION OF NEGATIVE IONS
      C
5     C      NEGATIVE ION SPECIES ARE STORED IN ARRAY NION
      C
      C      INDEX NION
      C
      C      1 O2-
      C      2 O4-
10    C      3 CO4-
      C      4 O3-
      C      5 CO3-
      C      6 O-
      C      7 NO2-
15    C      8 NO3-
      C
      COMMON NEUT(3,26)
      DIMENSION NION(8,26),K(100)
      REAL NION,K,LA,NEUT
      LOGICAL DAY
      IF(DAY) 1,2
1     1 D=1
      GO TO 3
2     2 D=0
25    3 O2SQ=NEUT(2,J)*NEUT(2,J)
      X=K(77)*O2SQ+K(80)*NEUT(3,J)
      B=NEUT(1,J)*(K(63)+K(64))+K(65)*NEUT(8,J)+
1     K(66)*O2SQ+D*K(91)+K(60)*NEUT(3,J)+AISP
      T=K(73)*NEUT(1,J)+K(74)*NEUT(5,J)+K(75)*NEUT(9,J)+D*K(94)+AISP
30    W=K(71)*NEUT(1,J)+K(72)*NEUT(6,J)+AISP
      V=K(68)*NEUT(3,J)+K(69)*NEUT(5,J)+K(70)*NEUT(1,J)+D*K(93)+AISP
      U=K(78)*NEUT(1,J)+X+D*K(92)+K(79)*NEUT(8,J)+AISP
1     +K(81)*NEUT(3,J)
      R=V*(U*W*T-D*K(94)*K(72)*NEUT(6,J)*X)
35    S=O2SQ*(W*U*K(66)*K(70)*NEUT(1,J)+U*K(66)*K(58)*K(72)*
1     NEUT(6,J)*NEUT(3,J)+V*K(64)*K(72)*K(77)*NEUT(1,J)*
2     NEUT(6,J))
3     +V*K(72)*NEUT(5,J)*NEUT(3,J)*(U*K(50)+K(64)*K(80)*
4     NEUT(1,J))
40    C
      C      NION(1,J)=O2-
      C
      NION(1,J)=(V*U*W*R*E*LA)/(R*B*V*U*W
1     -J*R*K(65)*K(68)*K(71)*NEUT(1,J)*NEUT(3,J)*O2SQ-
45    2     V*R*K(64)*K(71)*K*NEUT(1,J)**2-
3     S*V*NEUT(1,J)*(K(71)*X*D*K(94)+J*W*K(73))-
4     U*R*V*K(60)*K(71)*NEUT(3,J)*NEUT(1,J)
1     -W*V*K(64)*K(81)*NEUT(1,J)*NEUT(3,J)
50    6     -(S*W*V*K(81)*NEUT(3,J)*D*K(94))/2)
      C
      C      NION(2,J)=O4-
      C
      NION(2,J)=(K(66)*O2SQ*NION(1,J))/
1     (K(67)*NEUT(6,J))
55    C
      C      NION(3,J)=CO4-
      C
      NION(3,J)=(K(66)*O2SQ*NION(1,J))/
1     (K(68)*NEUT(3,J)+K(69)*NEUT(5,J)+K(70)*NEUT(1,J))

```

```

60      2      *D*K(93)+AISP)
      C
      C      NION(5,J)=C03-
      C
      NION(5,J)=S*NION(1,J)/R
65      C
      C      NION(6,J)=0-
      C
      NION(6,J)=(K(64)*NEJT(1,J)*NION(1,J)+D*K(94)*NION(5,J))/U
      C
70      C      NION(4,J)=03-
      C
      NION(4,J)=(K(68)*NEJT(3,J)*NION(3,J)+K(77)*NION(6,J)*02SQ+
1      NEUT(3,J)*(K(60)*NION(1,J)+K(80)*NION(6,J)))/W
      C
75      C      NION(7,J)=N02-
      C
      C=(D*K(96))/(D*(K(96)+K(97))+AISP)
      NION(7,J)=(K(74)*NEJT(5,J)*NION(5,J)+C*(K(75)*NEJT(9,J)*NION(5,J)+
1      K(69)*NEUT(5,J)*NION(3,J)))/
80      2      (K(75)*NEUT(3,J)+D*K(95)+AISP-C*K(75)*NEUT(3,J))
      C
      C      NION(8,J)=N03-
      C
      NION(8,J)=(K(75)*NEJT(9,J)*NION(5,J)+K(76)*NEUT(3,J)*NION(7,J)+
85      1      K(69)*NEJT(5,J)*NION(3,J))/
      2      (D*(K(96)+K(97))+AISP)
      SUM=0.
      DO 10 I=1,8
10      SUM=SUM+NION(I,J)
90      RETURN
      END

```

SUBROUTINE RATECN

```

1      SUBROUTINE RATECN(K,A,B,D,IREFAC,TEMP,IALT,NREAC)
      DIMENSION K(1),A(1),B(1),D(1),IREFAC(1),TEMP(1)
      REAL K
      DO 10 J=1,NREAC
5      ID=IREFAC(J)
      K(ID)=A(ID)*(TEMP(IALT)/300.)**B(ID)*EXP(D(ID)/TEMP(IALT))
10     CONTINUE
      RETURN
      END

```

DNA DISTRIBUTION LIST

Department of Defense

Director
Defense Advanced Research Projects Agency
1400 Wilson Boulevard
Arlington, Virginia 22209

1 cy ATTN: TIO
1 cy ATTN: STO
1 cy ATTH: NRMO

Director
Defense Communications Agency
8th Street and Courthouse Road
Arlington, Virginia 22204

3 cys ATTN: MEECN Office

Defense Documentation Center
Cameron Station
Alexandria, Virginia 22314

12 cys ATTN: TC

Director
Defense Nuclear Agency
Washington, D. C. 20305

1 cy ATTN: STTL
1 cy ATTN: DDST
3 cys ATTN: RAAE
1 cy ATTN: RAEV

Joint Chiefs of Staff
Department of Defense
Washington, D. C. 20301

1 cy ATTN: J-6

Director
National Security Agency
Fort George G. Meade, Maryland 20755

2 cys ATTN: Technical Library

Under Secretary of Defense (Research and Engineering)
Department of Defense
Washington, D. C. 20301

2 cys ATTN: DDS&SS

Department of Commerce

U. S. Department of Commerce
Office of Telecommunications
Institute for Telecommunication Sciences
National Telecommunications and Information Administration
Boulder, Colorado 80303

2 cys ATTN: W. F. Utlaut

Department of the Army

Commander/Director
Atmospheric Sciences Laboratory
U. S. Army Electronics Command
White Sands Missile Range, New Mexico 88002

1 cy ATTN: DRSEL-BL-SY-S
F. E. Niles

Director
U. S. Army Ballistic Research Laboratories
Aberdeen Proving Grounds, Maryland 21005

1 cy ATTN: George E. Keller

Commander
U. S. Army Foreign Sciences and Technology Center
220 7th Street, N.E.
Charlottesville, Virginia 22901

1 cy ATTN: Robert Jones

Department of the Navy

Chief of Naval Operations
Department of the Navy
Washington, D. C. 20350

1 cy ATTN: NOP 985
1 cy ATTN: NOP 094H

Chief of Naval Research
Department of the Navy
800 North Quincy Street
Arlington, Virginia 22217

1 cy ATTN: Code 465, R. G. Joiner
1 cy ATTN: Code 427, H. Mullaney

Commander
Naval Electronic Systems Command
Department of the Navy
Washington, D. C. 20360

1 cy ATTN: PME-117
1 cy ATTN: PME-117T
1 cy ATTN: PME-117-21
1 cy ATTN: PME-117-21A
1 cy ATTN: PME-117-22

Director
Naval Ocean Systems Center
Electromagnetic Propagation Division
271 Catalina Boulevard
San Diego, California 92152

1 cy ATTN: Code 2200, W. F. Moler
1 cy ATTN: Code 2200, Ilan Rothmuller
1 cy ATTN: Code 2200, John Bickel

Director
Naval Research Laboratory
4555 Overlook Avenue, S.W.
Washington, D. C. 20375

1 cy ATTN: Code 7700, Timothy P. Coffey
1 cy ATTN: Code 7709, Wahab Ali
2 cys ATTN: Code 7750, John Davis
1 cy ATTN: Code 2627

Commander
Naval Surface Weapons Center (White Oak)
Silver Spring, Maryland 20910

1 cy ATTN: Technical Library

Office of Naval Research Branch Office
1030 East Green Street
Pasadena, California 91106

1 cy

Department of the Air Force

Commander
Air Force Geophysical Laboratory, AFSC
L. G. Hanscom Air Force Base, Massachusetts 01731

1 cy ATTN: OPR, James Ulwick
1 cy ATTN: LKB, W. Swider
1 cy ATTN: LKB, K. Champion

Director
Air Force Technical Applications Center
Patrick Air Force Base, Florida 32920

1 cy ATTN: TD
1 cy ATTN: HQ 1035th TCHOG/TFS

Department of Defense Contractors

General Electric Company
TEMPO - Center for Advanced Studies
816 State Street
Santa Barbara, California 93102

1 cy ATTN: Warren S. Knapp
1 cy ATTN: DASIAC

Lockheed Missiles and Space Company
3251 Hanover Street
Palo Alto, California 94304

1 cy ATTN: J. B. Reagan
1 cy ATTN: W. Imhof
1 cy ATTN: Martin Walt

Mission Research Corporation
735 State Street
Santa Barbara, California 93101

1 cy ATTN: M. Scheibe
1 cy ATTN: D. Sowle

Pacific-Sierra Research Corporation
1456 Cloverfield Boulevard
Santa Monica, California 90404

1 cy ATTN: E. C. Field

Pennsylvania State University
Ionospheric Research Laboratory
College of Engineering
318 Electrical Engineering - East Wing
University Park, Pennsylvania 16802

1 cy ATTN: John S. Hisbet
1 cy ATTN: Les Hale
1 cy ATTN: A. J. Ferraro
1 cy ATTN: H. S. Lee

R&D Associates
4640 Admiralty Way
Marina Del Rey, California 90291

1 cy ATTN: R. Lelevier
1 cy ATTN: F. Gilmore
1 cy ATTN: R. Turco

The Rand Corporation
1700 Main Street
Santa Monica, California 90406

1 cy ATTN: Cullen Crain

Professor Chalmers F. Sechrist
155 Electrical Engineering Building
University of Illinois
Urbana, Illinois 61801

1 cy ATTN: C. Sechrist

Stanford Research Institute
333 Ravenswood Avenue
Menlo Park, California 94025

1 cy ATTN: Allen M. Peterson
1 cy ATTN: Ray L. Leadabrand